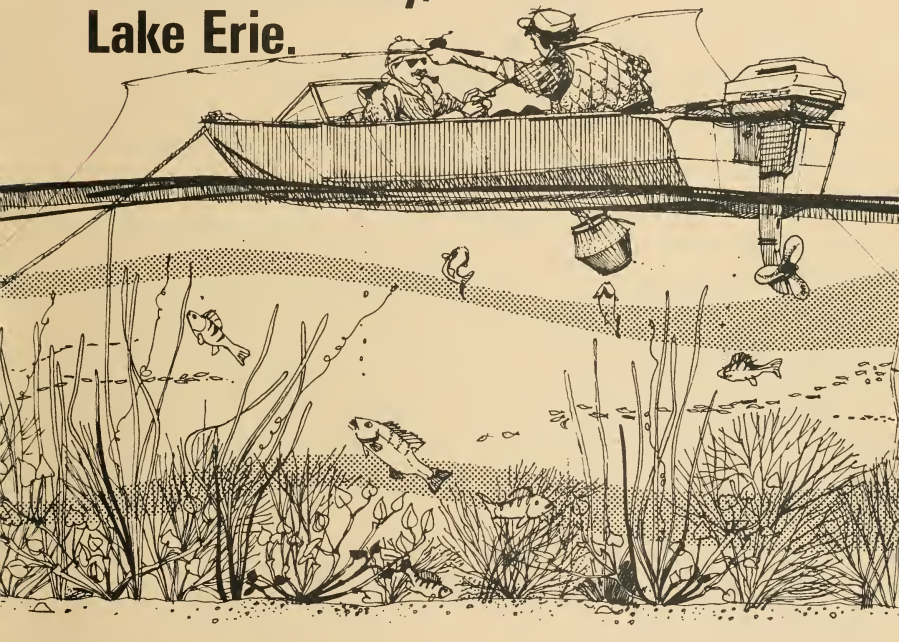
2309

A Management Strategy for the Restoration of Aquatic Vegetation in Rondeau Bay, Lake Erie.



Prepared for : Southwestern Region,
Ontario Ministry of the Environment

Prepared by : J E HANNA ASSOCIATES Inc.
MARCH 1984

TABLE OF CONTENTS

LIST OF FIGURES....iv
LIST OF TABLES....vi
ACKNOWLEDGEMENTS....vii

1 INTRODUCTION....1-1
1.1 Background....1-1
1.2 Study Objectives....1-2
1.3 Methodology....1-3

2 HYDROLOGY....2-1
2.1 Bathymetry....2-1
2.2 Watershed Characteristics....2-1
2.3 Water Levels....2-4
2.4 Water Budget....2-5

3 WATER QUALITY....3-1
3.1 Historical Conditions....3-1
3.2 Current Conditions....3-5
3.2.1 Suspended Solids (SS)....3-5
3.2.2 Phosphorus....3-15
3.2.3 Chlorophyll a....3-15
3.2.4 Water Clarity....3-20
3.2.5 Pesticides....3-20

4 VEGETATION....4-1
4.1 Historical....4-1
4.1.1. Aerial Photographs....4-1
4.1.2 Historical Records....4-7
4.2 Existing SAV Communities....4-9
4.2.1 Sampling Method....4-9
4.2.2 Distribution and Abundance....4-9
4.2.3 Community Descriptions....4-14
4.2.3.1 Community 1: H - M 4-14
4.2.3.2 Community 2: M - N 4-15
4.2.3.3 Community 3: V / H 4-15
4.2.3.4 Community 4: V - C 4-15
4.2.3.5 Community 5: P 4-16
4.2.3.6 Community 6: V - N 4-16
4.2.3.7 Community 7: V - H 4-16
4.3 Temporal Trends 4-17
4.3.1 Species Trends....4-17
4.3.2 Distribution and Abundance....4-18

5 SEDIMENTS....5-1
5.1 Sampling and Analysis Methods....5-1
5.2 Sedimentation History....5-1
5.3 Existing Sediment Characteristics....5-6
5.3.1 Particle Size and Organic Content....5-6
5.3.2 Phosphorus Content....5-8
5.3.3 Pesticides....5-8

5.4 Sediments Sources....5-9
5.5 Wave Climate....5-10
5.5.1 Sediment Resuspension....5-15
5.5.2 Physical Damage to SAV....5-16

6 AQUATIC ECOLOGY....6-1
6.1 Biological Interactions....6-1
6.1.1 Water Quality / Vegetation Interactions..6-1
6.1.2 Vegetation / Fisheries Interactions....6-3
6.1.3 Water Quality / Fisheries Interactions...6-4
6.1.4 Vegetation / Water Levels....6-4
6.2 Field Analyses....6-5
6.2.1 Standing Biomass....6-5
6.2.2 Seed Bank....6-6
6.3 Laboratory Experiments....6-6
6.3.1 Experimental Procedure....6-6
6.3.2 Effects of Sediment Type on Growth....6-9
6.3.3 Effects of Light Regime on Growth....6-11
6.3.4 Effect of Initial Biomass....6-11

7 ALTERNATIVE MANAGEMENT TECHNIQUES....7-1
7.1 Key Environmental Variables....7-1
7.1.1 Water Clarity....7-1
7.1.2 Wave Action....7-1
7.1.3 Plant Material....7-1
7.1.4 Other Environmental Variables....7-2
7.1.5 Habitat Diversity....7-2
7.2 Evaluation Criteria....7-2
7.2.1 Cost....7-2
7.2.2 Level of Technical Sophistication....7-2
7.2.3 Reliability....7-3
7.2.4 Flexibility....7-3
7.2.5 Permanence....7-3
7.2.6 Benefits....7-3
7.3 Management Techniques....7-4
7.3.1 Wave Barriers....7-4
7.3.2 Artificial Reefs....7-4
7.3.3 Sea Curtain....7-5
7.3.4 Alum Treatment....7-6
7.3.5 Natural Revegetation....7-6
7.3.6 SAV Seeding....7-7
7.3.7 SAV Transplanting....7-7
7.3.8 Soil Erosion Prevention....7-8
7.4 Summary....7-9

8 RECOMMENDED RESTORATION STRATEGY....8-1
8.1 Description of Recommended Strategy....8-1
8.2 Rationale for Recommended Strategy....8-3
8.3 Required Research Support....8-4
8.4 Schedule....8-5
8.5 Budget Estimate....8-6

9 BIBLIOGRAPHY....9-1

APPENDIX A EXPERTS CONTACTED
APPENDIX B PARTICLE SIZE DISTRIBUTION CURVES
APPENDIX C FIELD NOTES - WATER QUALITY
APPENDIX D FIELD NOTES - VEGETATION SAMPLES
APPENDIX E FIELD NOTES - SEDIMENT SAMPLES
APPENDIX F FIELD NOTES - DRAIN SEDIMENT SAMPLES
APPENDIX G FIELD NOTES - REPRESENTATIVE CORES
APPENDIX H FIELD NOTES - SEED BANK SAMPLES
APPENDIX I FIELD NOTES - GROWTH MEDIUM SEDIMENT SAMPLES
APPENDIX J GROWTH EXPERIMENTS - SUMMARY OF RESULTS

LIST OF FIGURES

Figure Number	Name	Page
1	Bathymetry	2-2
2	Watershed Hydrology - October 7, 1983	2-3
3	Secchi Disc Depth - August, 1975	3-3
4	Secchi Disc Depth - August, 1983	3-4
5	Secchi Disc vs Suspended Solids	3-7
6	Secchi Disc Depth April - May averages	3-11
7	Secchi Disc Depth June - July averages	3-12
8	Water Quality Sample Stations	3-14
9	Total Phosphorus vs Chlorophyll a	3-16
10	Suspended Solids vs Chlorophyll a	3-17
11	Chlorophyll a vs Secchi Disc	3-18
12	Suspended Solids & Chlorophyll a vs Secchi Disc	3-19
13	Light Transmission	3-21
14	Vegetation Distribution - July, 1955	4-2
15	Vegetation Distribution - July 1, 1973	4-4
16	Vegetation Distribution - September 1, 1978	4-6

17	Vegetation Sample Stations	4-12
18	Vegetation Distribution - August, 1983	4-13
19	Sediment Sample Stations	5-2
20	Surficial Sediments	5-4
21	Wind Rose April - May	5-11
22	Wind Rose June - July	5-12
23	Wind Rose August - September	5-13
24	Seed Bank Sample Stations	6-7
25	Cumulative Growth: Potamogeton - Reduced Light	6-12
26	Cumulative Growth: Potamogeton - Normal Light	6-13
27	Cumulative Growth: Potamogeton - Increased Light	6-14
28	Distribution and Phasing of Restoration Efforts	8-2
29	Cumulative Growth: Heteranthera - Reduced Light	J-8
30	Cumulative Growth: Heteranthera - Normal Light	J-9
31	Cumulative Growth: Heteranthera - Increased Light	J-10
32	Cumulative Growth: Vallisneria - Reduced Light	J-11
33	Cumulative Growth: Vallisneria - Normal Light	J-12
34	Cumulative Growth: Vallisneria - Increased Light	J-13

LIST OF TABLES

Table Number	Name	Page
1	Water Quality Data - August, 1983	3-6
2	Average and Ranges of Key Water Quality Parameters	3-9
3	Standing Biomass - August, 1983	4-10, 4-11
4	Results of Sediment Analysis	5-7
5	Wave Frequency and Height	5-14
6	Results of Sediment Seed Bank Analysis	6-8
7	Growth Response of *Potamogeton pectinatus* on Various Rondeau Bay Sediment Types	6-10
8	Cost Analysis for First Year of Restoration Program	8-7
9	Cost Summaries for Four Years of Restoration Program	8-8

ACKNOWLEDGEMENTS

This report was prepared under a professional services contract funded by the Southwestern Region of the Ontario Ministry of the Environment. A Technical Review Committee consisting of the following individuals oversaw the design and conduct of the work and provided valuable criticisms on the draft version of this report.

Peter Dillon, Research Scientist, Ontario Ministry of the Environment.

George Duckworth, District Biologist, Chatham, Ontario Ministry of Natural Resources.

Doug Huber, Regional Hydrologist, Southwestern Region, Ontario Ministry of the Environment.

Scott Painter, Research Scientist, Canada Centre for Inland Waters, Environment Canada.

Carl Schenk, Manager, Technical Support Section, Southwestern Region, Ontario Ministry of the Environment, (Committee Chairman).

Dennis Veal, Chief, Water Resource Assessment Unit, Southwestern Region, Ontario Ministry of the Environment.

John Westwood, Senior Biological Technician, Southwestern Region, Ontario Ministry of the Environment.

Ivey Wile, Program Analyst, Policy and Planning Branch, Ontario Ministry of the Environment.

During the course of the study valuable individual assistance was provided by the following people.

Ms. Ivey Wile prior to the initiation of this contract had compiled an extensive compendium of literature pertaining to aquatic macrophyte ecology all of which was made available to us. In addition she provided her expert opinion on macrophyte ecology and management throughout the study.

Mr. John Westwood has spent a great deal of time over the last 5 to 6 years working on the Bay and he gave freely of his knowledge and ideas. He assisted in initially orienting us to the Bay, organizing and explaining much of the data collected by the Ministry and later in collecting sediment samples and photometer measurements.

Mr. Scott Painter made available space and facilities at the Canada Centre for Inland Waters to conduct the laboratory growth experiments and to carry out some of the sample analyses. In addition, he readily gave advice and guidance concerning the technical aspects of experimental design and analysis.

Staff at Rondeau Provincial Park provided a boat and helper for several sample missions in late fall under less than optimal conditions.

The members of the project team responsible for conducting this work were:

Edward Hanna	Project Manager
Rysa Hanna	Botanist
Lauren Crooks	Environmental Technician
Ronald Phillips	Aquatic Macrophyte Specialist

The majority of the work associated with this project was undertaken by Ms. Lauren Crooks. Her multitude of skills ranged from hand-hauling the vegetation sampling cage full of mud and in rare cases aquatic plants into the boat, to setting up and monitoring the laboratory experiments, to data analysis and to much of the graphics in the report. Her unfailing commitment to the project was essential to its successful completion.

Ms. Rysa Hanna advised on the sampling design of the field and laboratory components, participated in all of the field investigations, coordinated much of the data analysis components and undertook taxanomic identification of plant specimens. She also critically edited the report.

Dr. Ronald Phillips acted as an expert advisor on aquatic macrophyte ecology, in particular rehabilitation techniques and strategies. He provided lists of experts around the world who were contacted in regards to information and experience relevant to the Rondeau Bay situation. Valuable insights as to primary consideration for transplanting of macrophytes and key site considerations were wisely given. Finally, he provided useful comments on the draft version of this report.

Mr. Edward Hanna provided liaison between the various individuals and agencies involved in the study and oversaw that schedule and budgetary constraints were met. He participated in the field investigations and was responsible for writing much of the report.

1 INTRODUCTION

1.1 BACKGROUND

Rondeau Bay, located on the north shore of Lake Erie, historically was characterized by luxuriant growths of submerged aquatic vegetation (SAV). The watershed consists of fertile loam and silty loam soils which are intensively cultivated for row crops. As a result, the Bay receives high loads of nutrients and sediments.

Rondeau had been reknown for its warm-water fishery, in particular large-mouth bass (Micropterus salmoides) and panfish, drawing fishermen from many parts of Canada and the United States. In the early 1960's, the Bay was invaded by Eurasian milfoil (Myriophyllum spicatum). Milfoil soon became the dominant species and extended in dense beds throughout the Bay, necessitating the Ontario government and private boating clubs to attempt to control the weed with herbicides and harvesters in the late 1960's and early 1970's. The chemical control methods were abandonned around 1975 due to their expense.

In the summer of 1977, local residents contacted staff of the Ontario Ministry of the Environment due to a sudden die-off of the milfoil. Similar die-offs were being noted at the same time in other lakes in Ontario and eastern North America. A number of causal agents have been postulated (eg. parasites, disease, nutrient limitation, build-up of toxins in sediments, climate, etc.), but no single explanation appears adequate to account for the observed milfoil collapse at all sites. (Similar collapses have been documented following milfoil invasions in other lakes after variable lengths of time.) In particular, the cause of the rapid reduction in milfoil abundance in Rondeau Bay has yet to be determined.

By 1978, only remanent stands of SAV were present; however, concurrently, an apparent reduction in the water quality of the Bay occurred. In particular, elevated suspended solids concentrations were noted. This change has been partially attributed to increased soil erosion in the watershed. However, with the loss of the dense milfoil beds, increased wave action appears to have reduced settling rates of suspended solids and increased resuspension of sediments. The associated reduction in light penetration due to high turbidity levels is a major barrier to the reestablishment of SAV.

Large areas of the Bay have remained virtually devoid of SAV since the 1977 milfoil collapse. Also the quality of the warm-water fishery has decreased significantly with an

associated loss in recreational fishing opportunities and tourism revenues for local businesses. The Ontario Ministry of the Environment has funded two separate studies to deal with the problem. The first, which was jointly funded with the Ontario Ministry of Natural Resources is now completed. A Master Erosion Control Program for the Rondeau watershed was developed (Ecologistics Ltd., 1983) and is currently in the implementation phase. The purpose of this program is to reduce soil erosion in the watershed and associated sediment loads to the Bay.

This report documents the results of the second study.

1.2 STUDY OBJECTIVES

The Rondeau Bay program has a number of overall objectives including:

a) To reduce erosional soil losses from the watershed.
b) To improve water quality in particular to reduce water turbidity.
c) To restore the warm-water fishery of the Bay.

The Master Erosion Control Plan was directed primarily toward the first objective and the recommendations contained in the report are now in the process of being implemented by the Rondeau Bay Watershed Agricultural Steering Committee. This study deals primarily with the second objective and indirectly with the third.

Specifically the following two objectives were addressed:

1) To assess the relationship between aquatic plant growth and environmental factors, with particular attention to turbidity, and

2) To assess the character of the Rondeau Bay benthic sediments.

Initially, these two objectives were seen as being quite separate from one another; however, as work progressed the close interrelationships between sediment deposition, aquatic plant distribution and water clarity became increasingly more apparent.

Accordingly, these two objectives were combined into one primary objective and several secondary objectives. The primary objective was:

> To develop a restoration strategy for submerged aquatic vegetation given current water quality conditions that would improve habitat for fish.

Associated with this primary objective were the following secondary objectives:

1) To characterize the current distribution of SAV in the Bay in terms of species, abundance, and physical site condition.

2) To map the benthic sediments of the Bay in terms of organic content, texture, and nutrients and to identify transport and deposition zones.

3) To evaluate the effect of water clarity on the growth of various SAV species.

4) To determine if any relationship exists between benthic sediment type and SAV growth.

5) To evaluate the natural regeneration potential of SAV from seeds contained in the sediments.

6) To develop a list of feasible management techniques, to assess their likely effectiveness and costs and to select the best areas for SAV restoration efforts.

1.3 METHODOLOGY

The objectives were achieved through a variety of techniques. A literature search and direct contact with scientists active in applied SAV research were undertaken. Information was requested from researchers in Canada, the United States, Europe and other parts of the world to assess the current understanding of SAV/water quality interactions and rehabilitation techniques. A complete list of individuals contacted is given in Appendix A.

An extensive field sampling program was conducted with a total of 30 man days spent over a four month duration. During this time, sediment cores were collected throughout the Bay and from all inflowing streams. In addition, representative intact cores were collected in plexiglass tubes for future reference. Grab samples of sediments were collected for future determination of the number and viability of SAV seeds. The distribution and abundance of SAV were quantified using a specially constructed dredge towed behind a boat. The dredge was dragged along the bottom and a series of teeth sheared SAV stems about 4 to 6 cm below the sediment interface and the stalks were collected in the mesh cage behind the teeth. The dredge contents were stored for later anlysis. Water quality samples and measurements were also taken during the field program. In particular, measurements of photosynthetic active radiation (PAR) at various degrees of water clarity were made using a photometer.

In addition to the field sampling, laboratory experiments were conducted using the five most common sediment types from the Bay and three native species of SAV, namely Potamogeton pectinatus, Heteranthera dubia and Vallisneria americana. The growth experiments were designed to assess the ability of the three species to adopt to transplant shock and to grow under varying light and sediment conditions.

The results of the analysis of the field and laboratory experiments were combined with the results of the Ministry of the Environment monitoring program to characterize the physical and biological environment of the Bay. On this basis, analogies with case histories reported in the literature were made and a restoration strategy for the Bay was devised.

The following report documents the results of these studies and outlines a recommended restoration strategy for the Bay.

2 HYDROLOGY

This section describes the physical characteristics of Rondeau Bay and its watershed in relation to its hydrology.

2.1 BATHYMETRY

Rondeau Bay is shaped like a plate with quite uniform bottom contours (Figure 1). The central deepwater zone is separated into two somewhat contiguous basins, the one in the north being about one third the size of the southern basin. The bottom slope along the western shore averages about 0.2% whereas the eastern shore slopes at about 0.8 to 1.0% out to the deep water zone. The mean depth of the Bay is about 1.95 m with a maximum depth around 3.5 m.

Running parallel to the eastern shoreline are a series of submerged beach ridges; they are part of the distinctive beach ridge deposition pattern evident along the length of Point Aux Pins. The submerged ridges extend out to about the 1.8 m contour.

Extensive areas along the western shoreline have been "reclaimed" for agricultural purposes. Rubble dikes have been extended out into the Bay and fill added behind or else pumped drainage systems have been constructed. The edge of the dikes are in water up to 1.2 m; approximately 30% of the length of the western shoreline has been dyked and/or filled.

2.2 WATERSHED CHARACTERISTICS

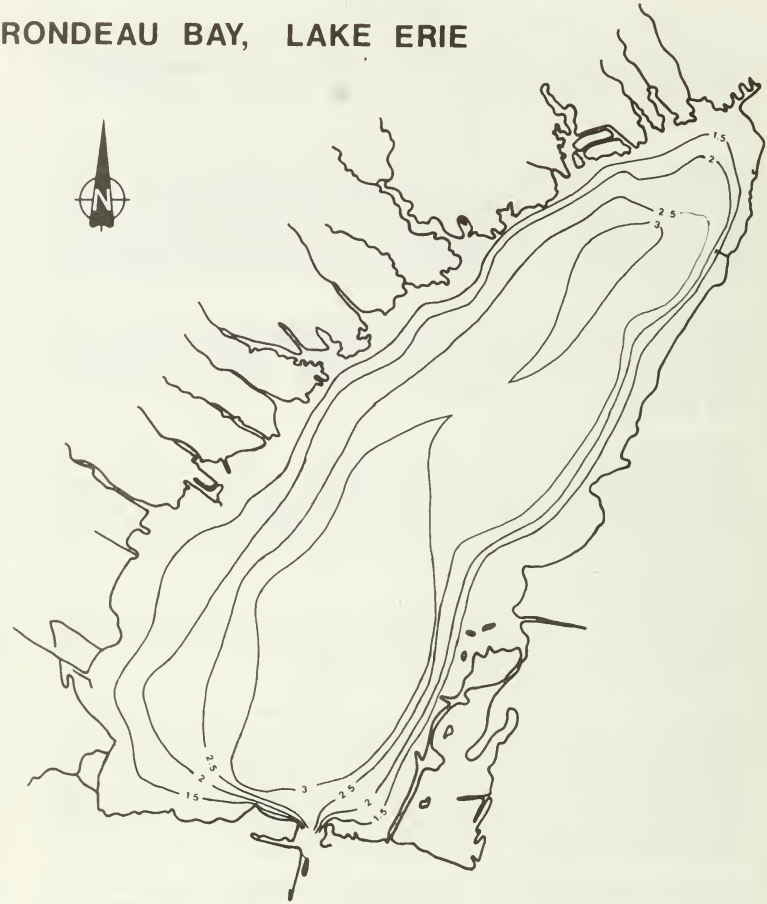
The watershed of the Bay extends over 103 km^2 of which over 90% is in agriculture-related uses. The drainage boundary bisects Blenheim (population 4,080) which is the only sizeable town in the watershed (Figure 2).

The soil characteristics of the watershed are described in detail by Ecologistics Ltd (1983) and consist primarily of loams and silty loams. The maximum topographic differential in the watershed is about 38 m above the level of the Bay and much of the area is fairly uniformly sloping averaging about 0.5% across the watershed. The only major topographic feature is the glacial Lake Warren shoreline which forms the headwaters for most of the streams flowing into the Bay.

Rondeau Bay is fed by 13 permanent streams and a number of smaller intermittent watercourses. The streams have characteristic dendritic drainage patterns and are evenly spaced along the western shoreline. No defined watercourses enter from the eastern shoreline.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

SOURCE: O.M.O.E.

JEHanna Associates Inc.	BATHYMETRY	FIG. 1

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

JEHanna Associates Inc.

WATERSHED HYDROLOGY
OCTOBER 7, 1983

FIG. 2

A single outlet located on the southern shore flows into Lake Erie. This channel was dredged for navigation purposes and is lined on both sides by concrete breakwalls. The minimum depth of the outlet is about 4 m and it is about 75 m wide.

2.3 WATER LEVELS

The water levels in Lake Erie have been recorded since 1916. A number of patterns are evident from this record.

i) Regular annual water level fluctuations in the order of 0.2 to 0.3 m have been recorded with the annual maximum level occurring normally in early to mid summer.

ii) A long-term cycle with a period of approximately 15 to 30 years marks periods of high and low water levels. Fluctuations over each cycle may be up to 1.6 m.

iii) Irregular daily fluctuations of up to 1 m can occur as a result of seiche. This effect occurs when strong winds are directly onshore or offshore and to a lesser extent when they set up parallel to the long axis of Lake Erie.

The short term fluctuations can have a dramatic effect on water exchange in the Bay. For example as shown in Figure 2, Lake Erie water is inflowing to the Bay. The winds in this case are onshore. With offshore winds, water is drawn out of the Bay causing water levels to drop. Lake Erie water will flow back into the Bay once these seiche effects subside.

The seasonal and long term fluctuations lead to a portion of the littoral zone experiencing periodic episodes of flooding and desiccation. This effect is particularly pronounced in a water body with a basin morphometry such as Rondeau Bay (see Figure 1); the very gradual slope of the bottom particularly along the western shore results in the effect of water level fluctuations extending over a considerable area.

These periodic fluctuations have implications in terms of sediment export out of the Bay and the oxidation of sediments and release of nutrients. During high water intervals, sediments are washed from the littoral zone into the deeper basin. Subsequently during low water intervals, this material is resuspended, part of which is flushed out into Lake Erie. This cyclic shift in levels maintains a well-scoured zone along the shoreline. SAV communities during low water intervals must retreat back from the shoreline but also can colonize deeper sections of the Bay. The reverse situation occurs during high water episodes.

Lake Erie is currently in the recessional stages of a high water interval. In 1973 and 1974 record high water levels were reached. The water levels in 1983 were about 0.4 m less than these maximum high levels. The last low point in the water level cycle was experienced in late 1964.

2.4 WATER BUDGET

Water quality in a lake is a dynamic phenomenon since water is continually flowing through the system. The throughput or flushing rate is important to understanding water quality conditions.

Calculations of flushing rate for Rondeau Bay are confounded by the frequent reversal in flow direction at the outlet to Lake Erie due to seiche. As a first approximation, it has been assumed that no seiches occur. An annual flushing rate has been calculated based on the following equation:

$$FR = \frac{Z * Ao}{(RR * Aw + (PR-ER) * Ao) * 10^{-2}}$$

where FR is the flushing rate (years)
Z is the mean depth of the Bay (m)
Ao is the surface area of the Bay (km^2)
RR is the runoff rate for the region (cm/yr) (from Pentland, 1968)
Aw is the watershed area (km^2)
PR is the annual percipitation rate (cm/yr) (from Brown et al, 1980)
ER is the evaporation rate (cm/yr) (from B. Finlayson, pers.comm.)

Entering the appropriate values and solving the equation.

$$FR = \frac{1.95 * 27}{(25.9 * 102.9 + (77.5-94.8) * 27) * 10^{2}}$$

$$= 1.7 \text{ years}$$

In other words, every 1.7 years the water in Rondeau Bay is replaced.

Introducing the phenomenon of seiches will tend to increase the exchange rate. During onshore winds Lake Erie water enters the Bay and with offshore wind levels drop, increasing the outflow from the Bay. The wind roses for the Rondeau area between April and October are discussed in Section 5.5.

Onshore winds (ie. S, SW, or SE) occur on a regular basis particularly during the summer months, and seiche effects are likely quite important during this time. However, a strict quantitative estimate of the effective flushing rate would require an indepth climatic and hydrological analysis.

This preliminary water budget calculation suggests that the Bay should not respond rapidly to individual runoff events. For example assuming a storm generates net runoff equal to 2.0 cm, the inflowing volume would equal 4 percent of the total volume of the Bay. However, the MOE monitoring program revealed considerable variations in water clarity, particularly in association with summer storms.

Several factors may explain these observations.

If inflowing waters have high levels of suspended solids, the total volume of water entering the Bay may be low (ie in the range of 4%) but the total load of suspended solids relative to average levels might be much higher. For example, suspended solids concentrations in runoff entering Rondeau were measured up to 63,250 mg/l after severe summer storms (Ontario Ministry of the Environment, 1982). With a dilution ratio of 1:25, this load would result in an overall concentration in the Bay of about 2,500 mg/l which is much above average levels of about 17.7 mg/l (see Section 3.2.1). This calculation assumes that rapid and extensive mixing of the Bay occurs; this assumption seems to be supported i) by various aerial photographs of the Bay (eg Figure 2) showing large-scale circulation patterns in the Bay, ii) its shallow depth, and iii) its large exposed surface area.

A second reason for highly variable suspended solids concentrations may be related to the internal generation of turbidity in the Bay. Wave action resuspends bottom sediments and increases turbidity (see Section 5.5.1). The relative importance of these two mechanisms is discussed later in the text.

3 WATER QUALITY

The physical environment is the foundation of all biological processes for both terrestrial and aquatic ecosystems. Given the dramatic decline in SAV abundance in Rondeau Bay, degradation of the physical environment is immediately suspected. To assess the significance of past changes in relation to current conditions, trend with time analyses must be combined with a characterization of current conditions. This section examines first the historical water quality conditions and changes thereto followed by a discussion of current conditions.

3.1 HISTORICAL CONDITIONS

The Ontario Ministry of the Environment has regularly sampled Rondeau Bay water quality since 1979. The program was initiated after the major decline in SAV in 1977 and therefore provides an excellent characterization of current conditions and seasonal variations in water quality. No comparable data are available prior to this time precluding before and after direct comparisons. A number of historical records were reviewed to gain some understanding of water quality prior to 1979.

The predecessor of the Ontario Ministry of the Environment, the Ontario Water Resources Commission, was actively involved in the mid to late 1960's and early 1970's supervising the application of herbicides to control extensive milfoil growth (Schenk, pers. comm.). Unfortunately, records of water quality measurements taken at that time have not been located.

Another source of historical water quality data is the aerial photographs which were used to map changes in the distribution and abundance of SAV (see Section 4.1.1). Relative water clarity can be obtained in some instances using this method. For example in the 1962 photographs, the submerged beach ridge formation along the eastern shore of the Bay is clearly visible. Lake Erie water levels at the time of the photographs, May 26, was approximately 173.8 m ASL. Based on the water depths recorded during the field sampling program of this project, the bathymetry map (see Figure 1), and current Lake Erie water levels (in August 1983, 174.5 m ASL) it is estimated that the Secchi disc depth in the Bay at the time of the photograph was in excess of 0.8 m. However, examination of photographs from July, 1955 and September 1, 1978 failed to reveal the presence of these

ridges and therefore Secchi disc depths are concluded to have been less than 1.4 m and 1.3 m respectively at these times. It should be noted that a variety of factors other than simply water clarity could explain the beach ridge patterns not being visible (eg angle of sun, wave patterns on water, etc.) and therefore it cannot be conclusively stated that Secchi disc depths were not equal to or greater than these values. Conversely though, the pattern in the 1962 photograph is conclusive evidence of the minimum Secchi disc depth.

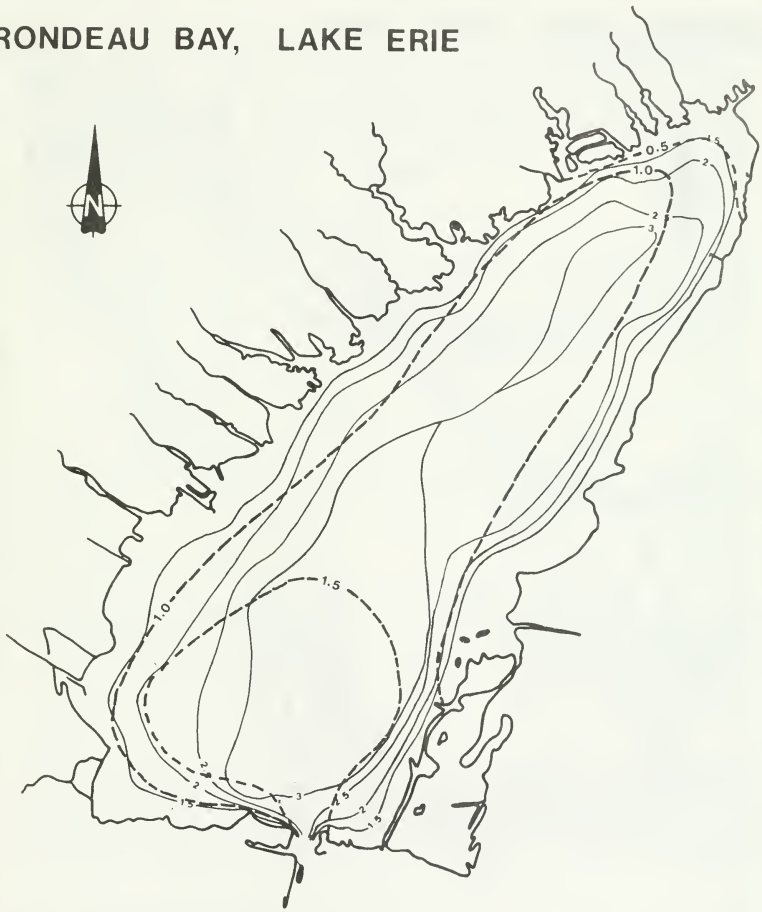
The Chatham District, Ontario Ministry of Natural Resources (OMNR) was approached concerning historical records which they might have available. Two reports were provided. One study by Sosiak and MacLennan (1975) was carried out as part of OMNR's ongoing aquatic habitat inventory program. The other report was prepared by Berst (1950) and focussed on the sports fishery of the Bay and contained several references to water quality.

The 1975 survey was carried out between August 26 and September 4, 1975. Reported Secchi disc depths ranged between .1 m and 1.5 m with average open water depths in the order of 1 m. No chlorophyll a or suspended solids concentrations were reported. Turbidity readings averaged about 20 JTU for the open water. While these are only a single set of samples and water clarity conditions in the Bay vary significantly on a short term basis according to runoff and wind conditions, they do provide an indication of the water quality conditions prior to the dieback of the milfoil. These measurements suggest that water clarity in the Bay has been reduced since 1975 by a factor of 2 to 3 times. Figures 3 and 4 graphically present the water clarity conditions in 1975 and at present.

The other available source of historical water quality data, the 1950 report by Berst, makes several references to water clarity and Secchi disc depth. On page 1 of the report, the author states that "[the] water in the bay remains turbid (seche [sic] disk reading of 1'-2') until about the end of May in each year, becoming clearer as the season progresses, until in the late summer or early fall we find a seche [sic] disk reading of 10'-12'." Later in the report on page 13, he mentions that "[before] May 20th the water in Rondeau Bay was so turbid (seche [sic] disk reading of 1.5' to 2.5') that observation of the bottom of the bay was impossible.". While Berst does not provide any systematic description of water clarity nor specific mapping of sampling sites, these general

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

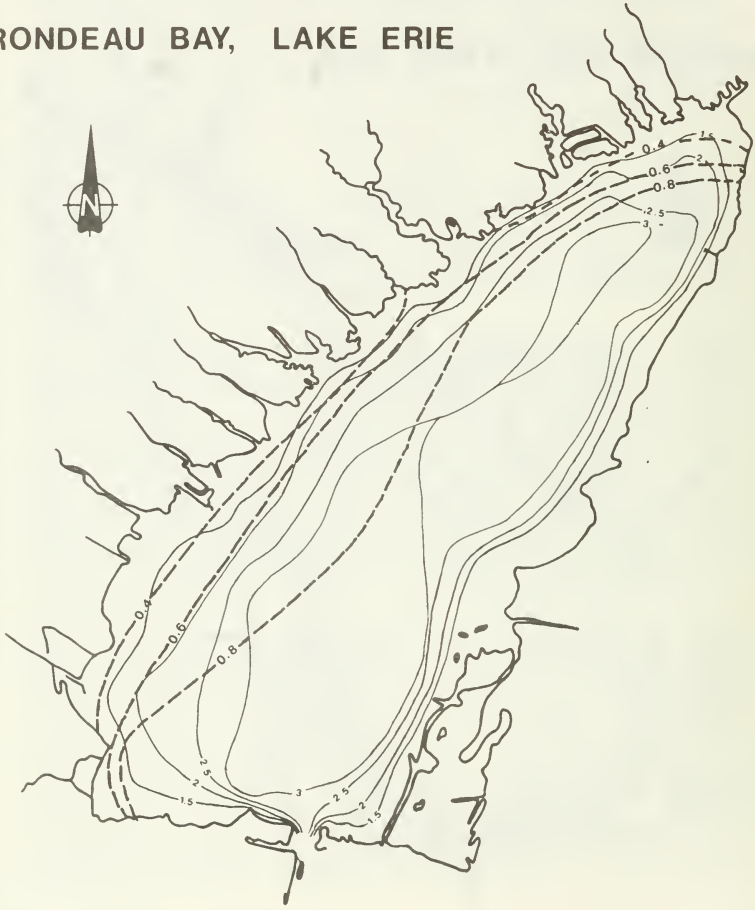
SOURCE: O.M.O.E.

----SECCHI DISC DEPTH (METERS)

JEHanna Associates Inc.	SECCHI DISC DEPTH AUGUST 1975	FIG. 3

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

-----SECCHI DISC DEPTH (METERS)

JEHanna Associates Inc.

SECCHI DISC DEPTH
AUGUST 1983

FIG. 4

statements and the notes in his report regarding observations of fish spawning in June suggest that water clarity was considerably greater than is currently the case.

None of the preceding information is fully definitive in itself but when considered jointly, it is concluded that a substantial reduction in water clarity conditions in the Bay has occurred at least since 1975. Degradation in quality may have begun much earlier since Berst reports Secchi disc depths in late summer of 2-2.5 m and those reported from the aquatic habitat survey conducted in late summer of about 1-1.5 m are clearly much reduced.

3.2 CURRENT CONDITIONS

The primary focus of this report is the restoration of SAV. Accordingly, the following discussion of water quality does not exhaustively treat all parameters but instead focusses on those which may have been altered in the Bay and which are of particular importance to macrophyte growth, specifically:

i) suspended solids
ii) phosphorus
iii) chlorophyll a
iv) water transparency
v) pesticides

A summary of the water analysis results from samples collected during the August field program are shown in Table 1.

3.2.1 Suspended Solids

This physical water quality parameter can have a major influence on SAV growth. The incident light available for photosynthesis at depth is partly a function of suspended solids concentration. Suspended solids are important also since virtually all ultimately originate from the surrounding watershed and are therefore directly linked to soil erosion control efforts.

Concentrations in the Bay are closely correlated with water transparency as shown in Figure 5, suggesting that suspended solids are the dominant parameter controlling light transmission to SAV. This curve is typical for light extinction relationships. At relatively low suspended solids concentrations, small changes in suspended solids cause large

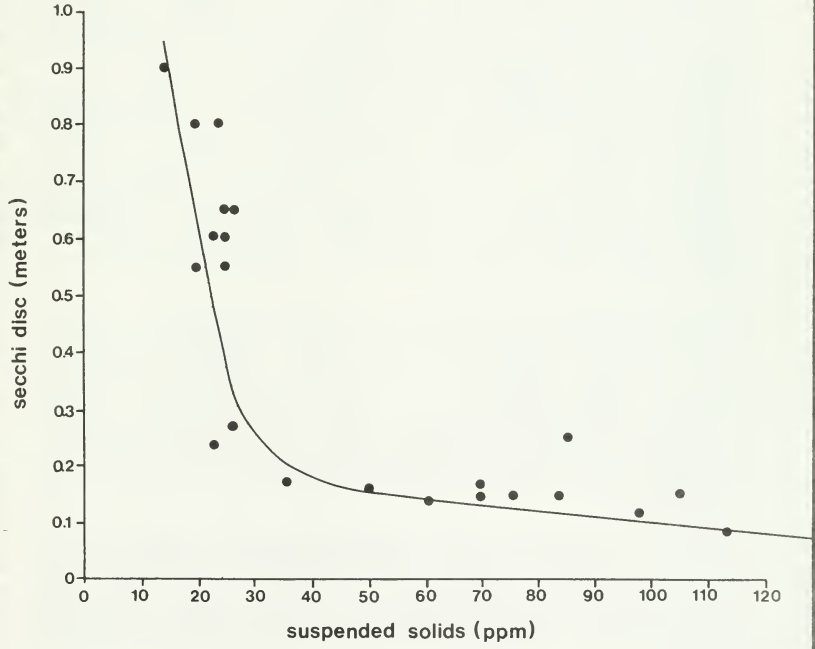
TABLE 1 WATER QUALITY DATA
Samples Collected August, 1983

Sample Number	Water Depth (m)	Secchi Disc. (m)	Turbidity (Formazin Units)	Suspended Solids (ppm)	Dissolved Reactive Phosphorus (ppm)	Nitrate (ppm)
1	2.05	0.9	13.2	14.8	0.002	<0.01
2	1.75	0.15	74	69.6	0.008	0.42
3	1.1	0.6	26	26.1	0.001	<0.01
4	1.9	0.55	16.7	20.1	0.001	<0.01
5	0.98	0.15	112	83.1	0.019	0.84
6	0.98	0.17	56	50.3	0.009	0.65
7	1.05	0.17	36	35.5	0.004	0.74
8	0.95	0.23	23	22.8	0.002	<0.01
9	1.0	0.14	77	60.2	0.009	0.04
10	0.7	0.15	83	70.0	0.008	<0.01
11	3.15	0.9	13.4	14.0	0.001	<0.01
13	1.9	0.65	20	27.9	0.001	0.43
14	1.1	0.28	26	27.1	<0.001	<0.01
14A	1.1	0.18	--	--	--	--
15	1.8	0.65	23	26.2	<0.001	<0.01
15A	1.8	0.55	--	--	--	--
16	2.55	0.8	21	19.6	<0.001	<0.01
16A	2.55	0.85	--	--	--	--
17	1.75	0.6	20	23.1	0.002	<0.01
17A	1.75	0.48	--	--	--	--
18	0.8	0.55	22	26.1	0.001	<0.01
18A	0.81	0.25	55	134.9	0.004	<0.01
20	2.95	0.8	22	23.1	0.001	<0.01
21	1.3	0.25	61	85.5	0.003	<0.01
22	0.75	0.15	77	105.6	0.003	<0.01
23	1.1	0.18	75	69.9	0.008	0.07
24	0.4	0.09	108	113.8	0.010	0.61
25	0.6	0.15	73	75.8	0.004	0.16
26	0.55	0.05	198	198.6	0.030	0.19
27	0.7	0.12	97	97.2	0.004	1.37
28	2.0	0.8	no results received			

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

Stations 1-27
August 18 & 19, 1983



JEHanna Associates Inc.	SECCHI DISC vs SUSPENDED SOLIDS	FIG. 5

reductions in light transmission and conversely at high suspended solids concentrations, major increases have little influence on light transmission. Currently, the average suspended solids concentrations in the Bay (Table 2) are in the middle range of the curve suggesting that increasingly greater water transparency will be obtained for each unit of suspended solids reduction.

This observation suggests that significant improvements in water clarity can be achieved in the Bay with the reduction of suspended solids through erosion control. Two factors need to be considered though.

First, no quantitative estimates have been made of the expected level of reduction of suspended solids that will be delivered to Rondeau Bay under various erosion control management practices in the watershed. Estimates that have been made pertain to total sediment yields (Ecologistics Ltd., 1983) and do not deal specifically with the fine fraction most susceptible to suspension in water. As a result, it is difficult to predict how much of a reduction in the measured suspended solids concentrations in the Bay can be expected with improved soil conservation practices. The actual volume of sediment required to maintain current suspended solids concentrations in the Bay has been calculated to be in the order of 1,060,938 kg. Average total sediment yield for the watershed is in the order of 40,850,527 kg per year (Ecologistics Ltd., 1983). In other words only 2.6% of the total soil eroded is required to create the current average suspended solids concentration in Rondeau Bay.

A second point to consider is that at the present time, suspended solids are the major factor contributing to reduced water transparency; however, given current nutrient concentrations, increases in chlorophyll a concentrations and reduced light transmission can be expected if suspended solids concentrations are reduced significantly. Some reduction in nutrient load will result from reduced sediment yields since much of the phosphorous is adsorbed to colloidal particles, but, relatively high phosphorous levels would be expected naturally in a fertile watershed like that of Rondeau Bay.

There is a seasonal trend in suspended solids concentration. This trend is reflected in Secchi disc depth readings; water clarity increases gradually from spring to fall. The trend to improved water quality over the growing season was also noted by Berst (1950). The degree of improvement is highly contingent on two factors, namely i) runoff and ii) wind/wave action.

A number of major storm events have been monitored by the Southwestern Region of the Ontario Ministry of the Environment (OMOE, 1982; J. Westwood, pers. comm.) and the results of this work clearly demonstrate the profound effect

TABLE 2 AVERAGE AND RANGES OF KEY WATER QUALITY PARAMETERS

Parameter	Summer Values (May - July) Average value	High value	Low value
Total Phosphorus (ppm)	.069	.152	.022
Dissolved Phosphorus (ppm)	.003	.009	.001
Chlorophyll a (ppb)	3.74	5.9	1.6
Nitrate (ppm)	0.133	.45	.03
pH	8.36	8.45	8.24
Suspended solids (ppm)	17.7	42.2	7.5
Turbidity (Formazin units)	10.3	27	3.6
Conductivity (umho/cm^3 at 25^o)	300	305	283

that intense storms can have on suspended solids concentrations in the Bay. Accordingly, reductions in suspended solids over the year is dependent on the frequency, intensity and temporal sequence of major storm/runoff events.

Spatial variation of suspended solids concentrations in the Bay reflects the location of sources, water current patterns, and wave exposure. Figures 6 and 7 depict average Secchi disc depths for two seasons of the year. The overall pattern in water transparency is clearly apparent. Along the western side where all the major inflowing streams are present, suspended solids concentrations are generally higher. Additionally, the northern end of the Bay has generally higher suspended solids concentrations than the south due both to wave action and to reduced water exchange with Lake Erie.

Water exchange with Lake Erie can affect suspended solids concentrations significantly. Figure 2 is an aerial photograph taken on October 7, 1971. In this example, onshore winds have set up a strong littoral transport system along the Lake Erie shoreline and this suspended material is being carried into Rondeau Bay increasing water turbidity. The inflow of water is due likely to seiche (ie. the increase in Lake Erie water level on the windward shore due to wind).

At the present, however, water clarity in Lake Erie is much greater than in Rondeau Bay. For example, Secchi disc depths in Lake Erie 300-400 meters out from the harbour mouth at Erieau in July 1983 were in the order of 8 to 9 m compared to less than 1 m in the Bay opposite the harbour. In most cases, inflowing Lake Erie water dilutes the suspended solids and increases water transparency. The frequency of this effect is dependent on wind direction and strength (see Section 5.5).

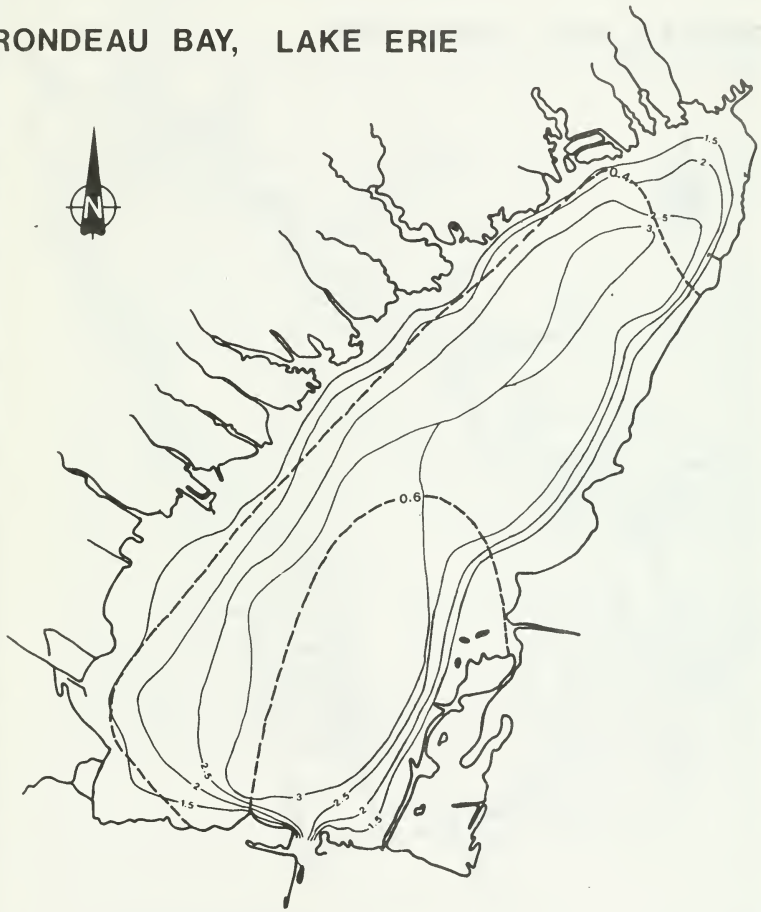
The large partially contained bay in the extreme southeastern section consistently has the lowest suspended solids concentrations in Rondeau Bay. It also supports the most diverse and dense SAV growth. Considerable attention was given to this site in attempting to understand the interaction of water quality and SAV growth.

Transects were run through the area in an attempt to determine the effect, if any, of the SAV on improving water quality. The following observations were made.

i) SAV growth was much reduced as the barrier sand beach separating Rondeau from Lake Erie was approached although water depth did not change appreciably. (The reduction in SAV density was likely due to substrate. See Section 4.2.2)

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours · meters

SOURCE: O.M.O.E.

---- SECCHI DISC DEPTH (METERS)

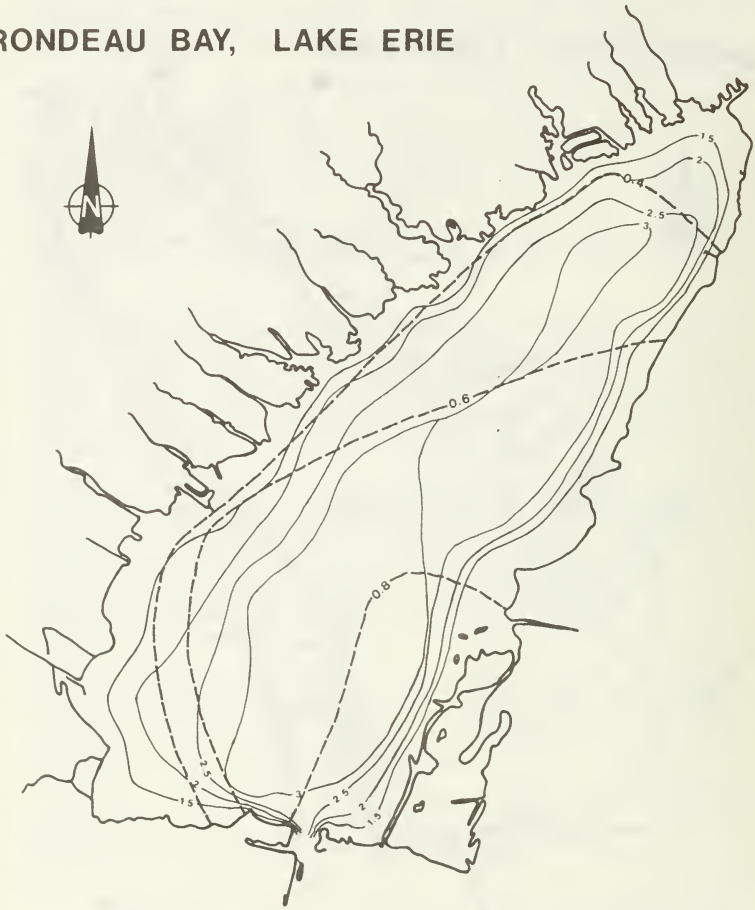
JEHanna Associates Inc.

SECCHI DISC DEPTH
APRIL-MAY AVERAGES

FIG. 6

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

-----SECCHI DISC DEPTH (METERS)

SOURCE: O.M.O.E.

JEHanna Associates Inc.	SECCHI DISC DEPTH JUNE-JULY AVERAGES	FIG. 7

ii) Water clarity improved as the barrier sand beach was approached despite a significant reduction in SAV abundance.

iii) Water clarity decreased significantly from east to west with the major zone of transition coincident with the crests of the submerged beach ridges separating this small bay from the main part of Rondeau.

Given these observations, it was concluded that the enclosed bay was being supplied with water infiltrating from Lake Erie through the barrier beach and that the SAV in combination with the submerged beach ridges prevented mixing of the turbid Rondeau water with the infiltrating Lake Erie water maintaining a contained zone of relatively clear water.

The question remains as to whether SAV actually directly improves water clarity significantly. Kemp et al (1982) state that "both chlorophyll-a and suspended particulate concentrations were lower within SAV communities than in non-vegetated littoral areas, and the differences were greatest at low slack tide, probably due to settling of particulates in the quiescent waters of the bed.". These data support qualitative observations made by OMOE staff (J. Westwood, pers. comm.) and during the field work component of this study that differences in water clarity were apparent in large dense clumps of H. dubia. The net effect of SAV on water quality is highly dependent on resuspension of deposits through wave and current turbulence. A more significant effect of SAV on reducing suspended solids concentrations results from wave attenuation and associated reductions of sediment resuspension (see Section 5.5).

The spatial distribution of suspended solids due to the short term effects of wave action was examined during the field sampling program. A series of water quality samples were taken at variable distances out from shore before and during a moderate onshore wave event (Stations 14-18, Figure 8). The changes in suspended solids are discussed in Section 5.4. This example demonstrated that near-shore water clarity along the western shore is sensitive to wave action and is subject to greater temporal variations than is the central open water zone of the Bay.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

SCALE 1:50,000

Depth contours: meters

JEHanna Associates Inc.	WATER QUALITY SAMPLE STATIONS	FIG. 8

3.2.2 Phosphorus

The primary limiting nutrient for the growth of phytoplankton (free floating cellular aquatic vegetation) and SAV in most aquatic systems is phosphorus. Accordingly attention has been focussed on this essential nutrient.

Phosphorus concentrations are high in the Bay, with total phosphorus averaging 69 ppb and dissolved active phosphorus averaging 3 ppb. These levels are in the range characteristic of eutrophic water bodies (Vollenweider, 1968) and are likely due to high inputs of adsorbed phosphorus on eroded soil particulates.

These concentrations are adequate to support extensive SAV growth; in fact, based on experiments conducted as part of the Chesapeake Bay research program, these high levels of phosphorus may be a significant factor contributing to the limited distribution and abundance of SAV in Rondeau Bay (Kemp et al, 1982). This relationship is discussed further in Section 6.1.1.

3.2.3 Chlorophyll a

Chlorophyll a is a pigment in the cells of plants that is used in photosynthesis; chlorophyll a concentrations reflect the density of phytoplankton in water, higher concentrations relate to denser populations. In many water bodies, phytoplankton is the major determinant of water clarity.

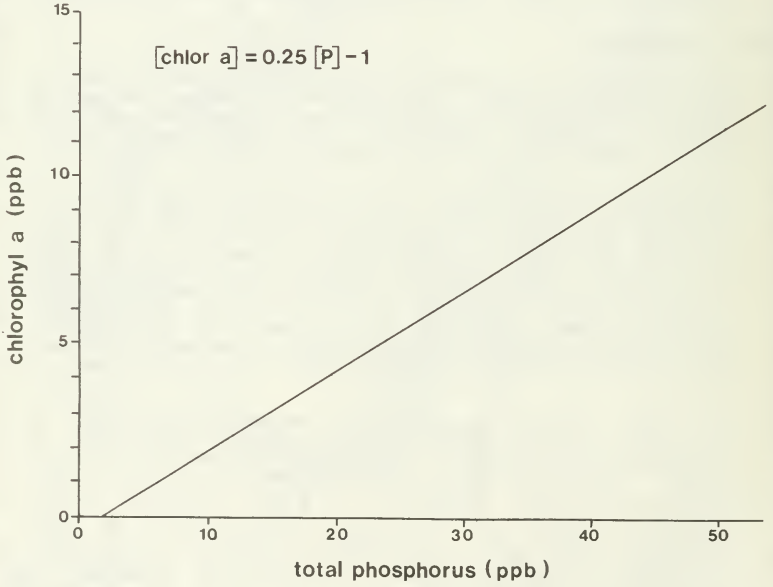
Chlorophyll a concentrations can be predicted from phosphorus concentrations (Figure 9). Given current phosphorus levels, expected chlorophyll a concentrations would be in the range of 16.25 ppb; however, summertime averages are in the order of 3.74 ppb. The difference is due to the reduced light availability caused by high suspended solids concentrations. In other words, nutrients are not limiting phytoplankton growth; instead, growth is light limited. If all suspended solids were eliminated and chlorophyll a averaged 16.25 ppb, the expected Secchi disc depth would be in the order of 0.9 m.

A weak inverse relationship between chlorophyll a concentration and suspended solids is seen in Figure 10. As suspended solids increase, chlorophyll a decreases and visa versa. The limited effect that phytoplankton has on water clarity is shown in Figure 11. When suspended solids concentrations are added the fit of the curve is much improved (Figure 12). These data demonstrate that water clarity in the Bay is determined primarily by inorganic suspended solids and that a significant increase in phytoplankton concentrations can be expected if suspended solids concentrations are reduced significantly.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

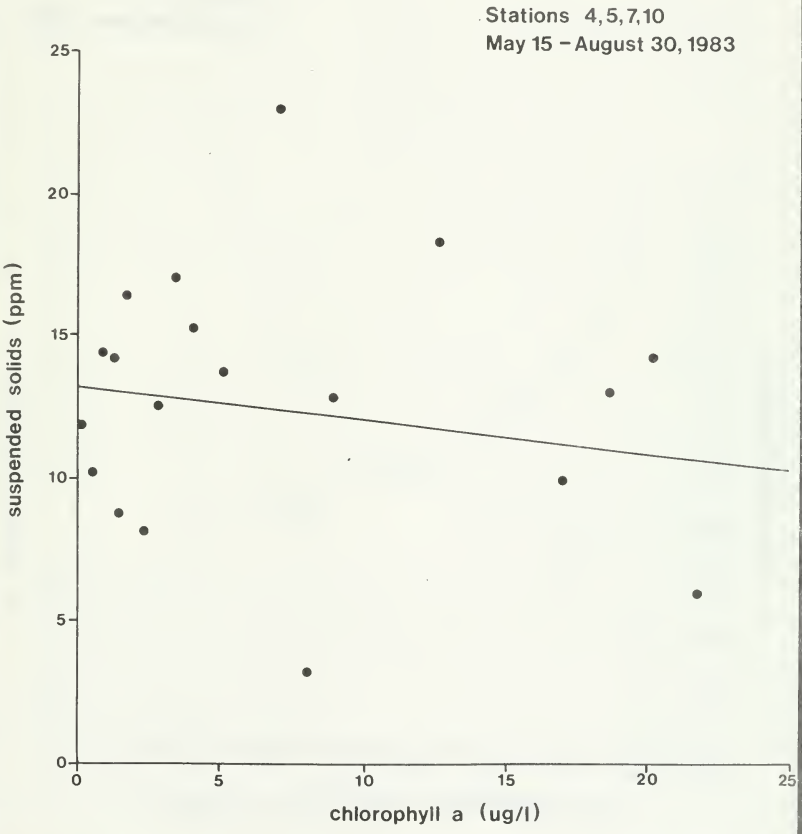
SOURCE: ROY, 1979



JEHanna Associates Inc.	TOTAL PHOSPHORUS vs CHLOROPHYLL A	FIG. 9

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



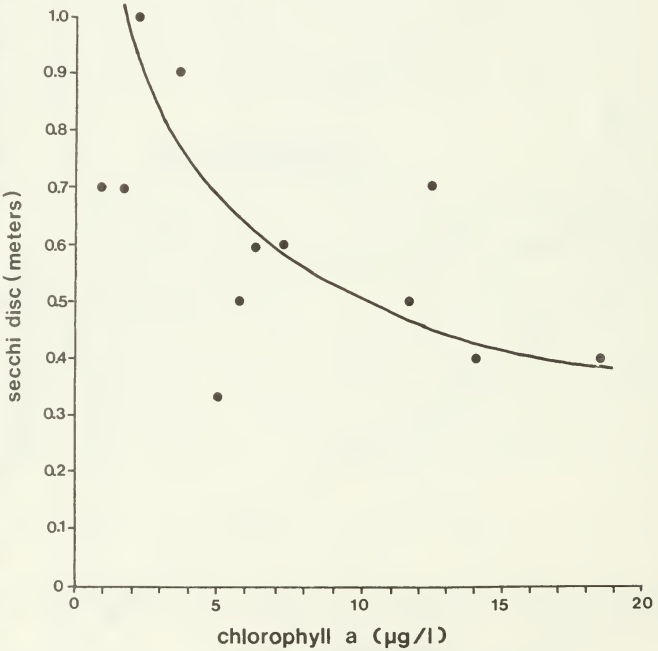
SOURCE: O.M.O.E.

JEHanna Associates Inc.	SUSPENDED SOLIDS vs CHLOROPHYLL A	FIG. 10

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

Station 7
April-September, 1983



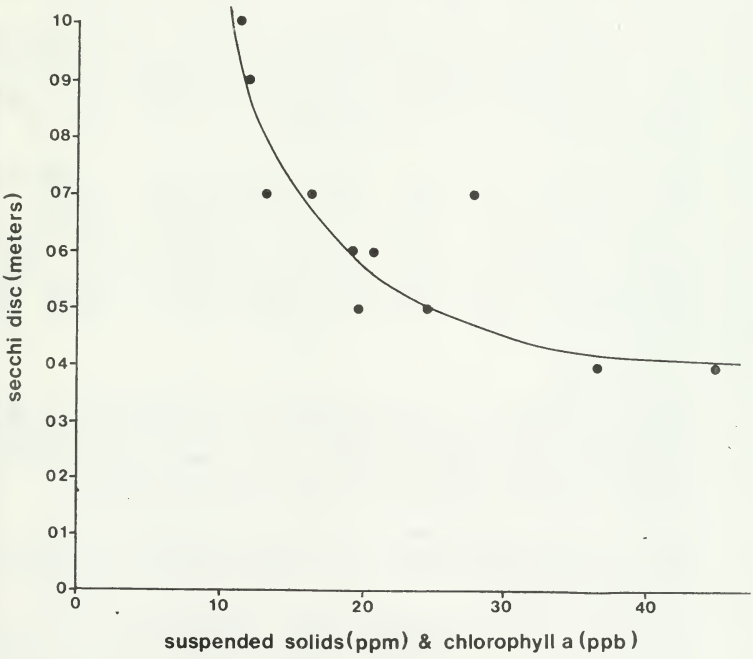
SOURCE: O.M.O.E.

JEHanna Associates Inc.	CHLOROPHYLL A vs SECCHI DISC	FIG. 11

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

Station 7
April – September, 1983



SOURCE: O.M.O.E.

JEHanna Associates Inc.	SUSPENDED SOLIDS & CHLOROPHYLL A vs SECCHI DISC	FIG. 12

3.2.4 Water Clarity

Secchi discs are simple instruments designed to measure water clarity. By recording the depth at which the disc disappears, the euphotic zone which is the depth of light penetration can be approximated by doubling the depth reading.

A more sophisticated instrument called a photometer is used to measure directly, incident photosynthetically active radiation (PAR). Light in the range of 400 to 700 nm is used by most SAV for photosynthesis rather than the full visible light spectrum (Sculthorpe, 1967). Secchi disc readings measure transmission of visible light and not just PAR.

A close correlation exists between water clarity measurements using Secchi discs and light transmission levels recorded with photometers (Figure 13). This suggests that the historical Secchi disc readings do provide reasonable approximations of light availability for plant growth in Rondeau Bay.

Current water clarity conditions indicate that the euphotic zone during the critical early growing season (ie May to July) averages about 1.0 to 1.6 m. In order for most species of SAV to survive, they must have a significant portion of their leaf surface within this zone for much of the growing season. Therefore plants growing in water depths in excess of about 1.0 m must extend shoots up from the sediments into the euphotic zone before net accumulation of energy and biomass will begin.

3.2.5 Pesticides

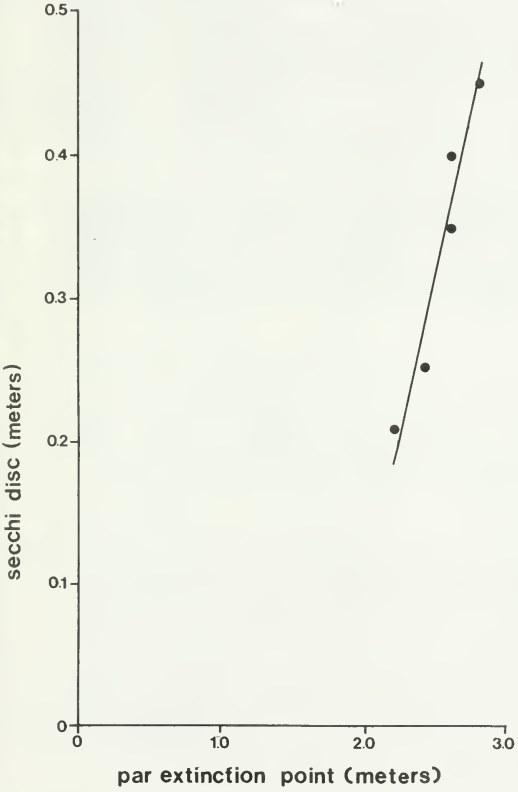
Analyses of water for pesticides have been conducted by the Ontario Ministry of the Environment for samples collected throughout the SAV growing season in 1983 and for samples collected in mid summer of 1977. They were collected from the major drains entering the Bay and were analyzed for the primary herbicides used by the local farming community.

The 1977 analyses found trace amounts of atrazine (ie 0.1 ppb) in one water sample. All other sediments and samples had water concentrations below detectable limits for all chemicals tested.

Most of the 1983 samples had undetectable or trace concentrations of herbicides. However, one series of samples taken in July from inflowing drainage ditches after a major runoff event had elevated levels of a variety of herbicides. Atrazine levels ranged between 1.3 and 75.8 ppb; however, no indication is given regarding the duration of these levels.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	LIGHT TRANSMISSION	FIG. 13

Based on the levels recorded in other samples during normal flow, the elevated concentrations likely followed the runoff pattern and lasted from 12 to 24 hours.

Fairly extensive experiments regarding atrazine toxicity have been conducted as part of the Chesapeake Bay studies (Correll and Wu, 1982; Kemp et al, 1982; Forney and Davis, 1981). Sensitivity between species was noted (eg M. spicatum was found to be most tolerant and V. americana was found to be most sensitive) but the general conclusion from these studies is that "the ephemeral nature of ... elevated herbicide levels and the tendency toward rapid photosynthetic recovery in these plants would render such effects short in duration." (Kemp et al, 1982). In addition they found that "at concentrations less than 100 ppb of atrazine, plants exhibited a significant trend of photosynthetic recovery within 1-2 weeks after initial exposure despite the continued presence of herbicides in microcosm waters".

These results and the distribution and abundance of SAV in the drainage ditches suggest that herbicides in the water may periodically stress SAV and reduce photosynthetic production temporally but that these chemicals are not a major constraint to SAV growth. A similar conclusion is reached regarding herbicide concentrations in the sediments (see Section 5.2.3).

4 VEGETATION

This section describes the historical and current characteristics of the SAV communities of Rondeau Bay. Particular attention is given to those features of the plant communities which are important to future restoration efforts.

4.1 HISTORICAL

Two primary sources of historical information are available describing SAV distribution and abundance in the Bay, namely archival aerial photographs and records of earlier surveys.

4.1.1 Aerial Photographs

The most definitive and reliable source of information is archival aerial photographs dating back to the 1950's. A list of the date, scale, type and source agency of air photos available for Rondeau Bay was compiled by Mann and Coakley (1978). There are some omissions in the list and some photographs have been taken since the report was written but it does provide a reasonably comprehensive summary. Aerial photographs taken between May and September were examined for the following years: 1955, 1962, 1970, 1973, 1978, 1980.

The distribution, relative abundance and apparent species composition were mapped.

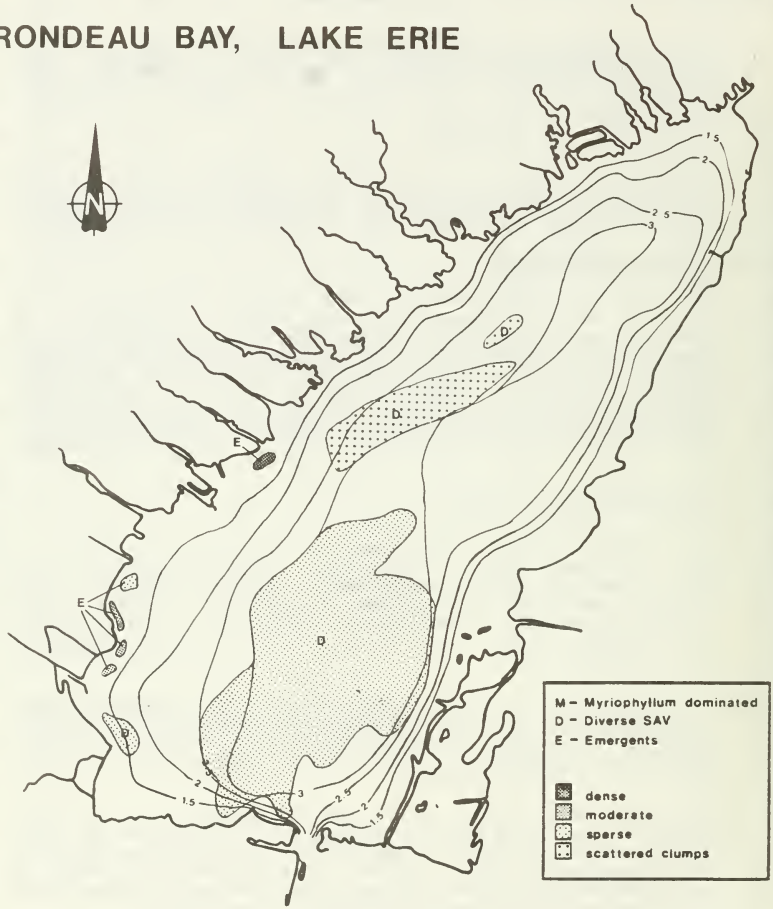
The 1955 photographs were taken in July and water levels in Lake Erie were about 174.2 m ASL. The photographs are of poor quality with considerable glare; however, some communities of SAV were evident (Figure 14). A large stand of SAV is apparent in the deepest zone of the southern basin. The pattern suggest that one or more species of Potamogeton were present.

Several stands of emergent vegetation, likely Nuphar advena or Nymphaea sp. are apparent along the shore in the southwest section of the Bay. In addition, smaller stands of SAV were growing in the southern two-thirds of the Bay; these are less dense than the major stand.

The water appears turbid in these photographs. It is quite feasible that much more extensive SAV are present but they are not evident. This is particularly true for species such as V. americana that do not form surface canopies. There is no evidence in the photographs of the extensive milfoil beds which are apparent later in the 1960's and 1970's.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

JEHanna Associates Inc.	VEGETATION DISTRIBUTION JULY 1955	FIG. 14

The 1962 photographs were taken in late May. The water was moderately turbid and only small stands of SAV are apparent. It is likely that much of the vegetation had not fully extended into the near surface zone and was therefore not visible.

Extensive milfoil beds are evident in the 1970 photographs taken in late June. Dense beds of this species are apparent along both the east and west shores extending most of the way up to the north end. The water appears less turbid than in earlier photographs and boat channels formed either by a weed cutter or herbicides are clearly visible. The beds in 1970 were similar in extent to those mapped for 1973 (see Figure 15) but extended slightly further into the deepwater zone of the northern basin. In these photographs, the milfoil was growing in water out to about 3.0 m. Water levels in 1970 at the time which the photographs were taken was 174.2 m ASL about 0.5 m less than the level recorded when the 1973 photographs were taken (ie 174.7 m ASL).

The SAV distribution for 1973 is shown in Figure 15. Some general patterns are evident.

i) The most dense and continuous beds occurred in the southeast sector of the Bay, the area where the most abundant SAV occurs today.

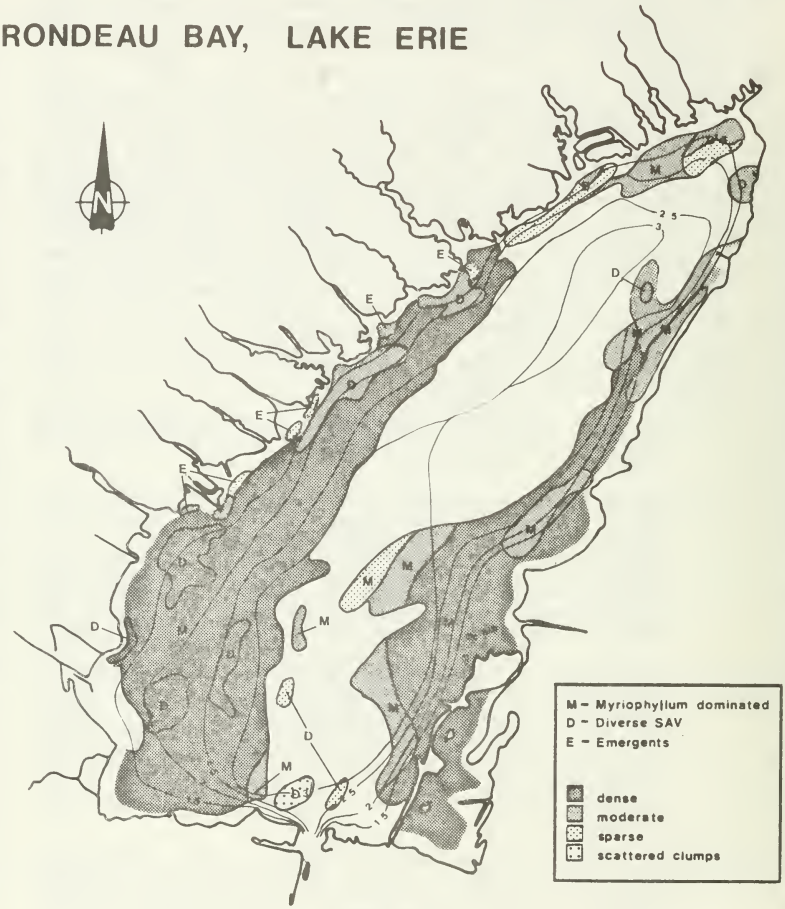
ii) Milfoil was the dominant SAV species and diverse other species were absent except for i) along the edges of the milfoil beds, ii) several open water stands and iii) one large stand in the southwest sector of the Bay. It appears that either the milfoil effectively outcompeted native species (which is a common occurrence with milfoil invasions) or that it was more tolerant to the chemical and mechanical control methods being employed.

iii) The stands of SAV observed on the 1955 photographs and to a lesser extent on the 1962 photographs have all but disappeared in the central parts of the southern basin. This is not likely due to competition since the milfoil never grew in this zone. The beds may have been adversely affected by mechanical and/or chemical SAV control tehniques or they might not have been able to tolerate the high water levels and reduced light transmission.

iv) The milfoil had not established dense beds in the deeper water and was quite limited in the most wave exposed sections of the northern basin. Although water levels differed by 0.5 m between 1970 and 1973, milfoil distribution in the deeper sections of the Bay was reduced only slightly.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1 50,000

Depth contours meters

JEHanna Associates Inc.

VEGETATION DISTRIBUTION
JULY 1 1973

FIG. 15

v) Scattered beds of emergent vegetation were present along the western shoreline where protection was offered by dense milfoil beds offshore.

vi) The milfoil beds did not extend to the immediate shoreline. This may partly reflect both annual and long-term water level cycles. Early summer is typically the time at which water levels peak in Lake Erie. Annual variations are in the order of 0.4 to 0.5 m. In addition, the all time record high water level for Lake Erie in June and July occurred in 1973 (see Section 2.3). Drawdown has been used as a method to control milfoil (Holcomb et al, 1975) and the shoreline zone with no milfoil may partly reflect this effect. Finally, milfoil generally does not grow extensively in water depths less than about 1 m (Adams and Prentki, 1981).

The 1978 distribution of SAV shows the dramatic change which occurred around 1977 (Figure 16). This map was derived from photographs taken in early September 1978, the time of year when SAV biomass is at its maximum. Water levels in Lake Erie were about 174.2 m ASL which are comparable to the 1970 levels. Virtually all of the stands of SAV were gone from the open water zone over about 2.0 m. No stands dominated by milfoil were present and none of those remaining exhibited dense growth; generally they were sparse or consisted of scattered clumps. The only area that appears relatively unaffected were the backwater areas behind the submerged beach bars on the eastern shore. Most of the residual stands on the western shore were close to the mouths of drainage ditches. The water is quite turbid and submerged beds of species such as V. americana would not be visible.

The distribution of SAV on the 1980 photographs revealed a pattern similar to 1978 with much of the SAV concentrated along the shorelines. The water in these photographs was very turbid and sparse beds of SAV could have been overlooked.

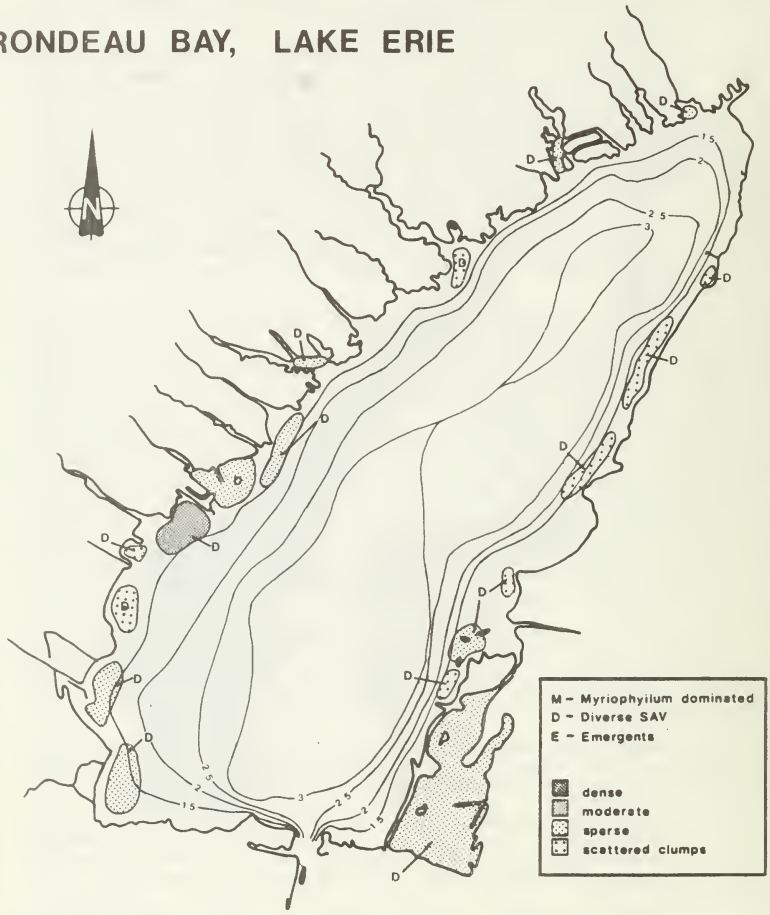
In summary, the series of archival aerial photographs evinced the following characteristics and trends in historical SAV distribution and abundance.

i) Parts of the Bay appear to have never supported dense SAV growth from 1955. In particular, the central portion of the northern basin and much of the exposed shoreline zone in the northern sector of the Bay.

ii) Native stands of SAV appear to have diminished or disappeared completely with the milfoil invasion and they persisted only as remnant stands primarily in areas where they were historically abundant.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

JEHanna Associates Inc.

VEGETATION DISTRIBUTION
SEPTEMBER 1 1978

FIG. 16

iii) Dense beds of milfoil are apparent in 1970 and 1973 extending across most of the southern sector of the Bay. The species seemed to have reached a maximum distribution by this time since the boundaries of the beds are quite similar between these two years.

iv) A dramatic reduction in the distribution and abundance of SAV is evident between the 1973 and 1978 photographs. Remnant stands have lower stalk densities and are restricted to protected shoreline sites.

4.1.2 Historical Records

Three sources of records describing SAV abundance and distribution are available, namely:

i) Rondeau Bay Fisheries Survey (Berst, 1950)

ii) Survey of Rondeau Harbour (Sosiak and MacLennan, 1975)

iii) Rondeau Park Draft Master Plan (anon., n.d.).

None of these reports are based on quantitative SAV survey techniques, but they do provide anecdotal notes to corroborate in a general sense the airphoto interpretation.

Berst (1950) stated in his report that "[about] 50 percent of the bottom of the bay supports a luxurious growth of a great variety of water plants. Each summer there is a phenomenal growth of these plants in large areas in the bay, and each winter they decrease to a minimum as the water cools and the ice and snow cover shuts out part of the sun's rays." Although the 50 percent appears to be a crude estimate, it does match generally with the observation that large areas in the northern basin of the Bay plus some of the deeper and/or exposed sections of the southern basin were not vegetated.

Another point can be inferred from his observations. That is large-mouth bass spawning was concentrated in the three areas where historically and currently the most extensive beds of SAV were and are located. Large-mouth bass prefer shallow weedy habitat for spawning and nursery areas and also as cover for adult fish and it is likely therefore that these major spawning areas correlated to a certain extent to shallow-water SAV distribution and abundance. The three areas identified were i) the extreme southwest corner, ii) the southeast corner behind the submerged beach ridges and iii) the next bay north on the east shore. These areas also were where the highest densities and diversities of SAV were encountered in 1983.

The 1975 survey was based on aquatic habitat survey techniques developed by the Ontario Ministry of Natural

Resources for lakes and the results were reported on standard survey data sheets for a total of eight stations sampled in late August and early September. They observed no SAV growing in the 2 open water stations in the southern and northern basins but found dense SAV along the shoreline and in the southwest sector of the Bay. Unfortunately the only genus of SAV mentioned is Chara, although comments on abundance such as "none apparent", "little apparent" and "very dense" do provide some qualitative insights. In general, the distribution of SAV reported at these eight stations corresponds with distributions and abundance interpreted from the 1973 photographs.

The draft master plan report (anon., n.d.) states that "[during] August of 1977 the Ministry of Natural Resources Aylmer District Fish and Wildlife Section observed aquatic vegetation growing at the 1975 Fisheries Survey Stations within Rondeau Bay ... and produced the following list of species and observations by station". The report then goes on to provide station by station summaries of species presence and subjective abundance assessments. The accuracy of the species identified is questionable; it is likely that a number of species are incorrect (eg P. vaginatus is likely H dubia; P. filiformis is likely P. pectinatus, M. verticillatum is likely M. spicatum.). Given these limitations the following comments can be made.

i) Sites located in the backwater areas along the eastern shore had high species diversity and abundance.

ii) The open water stations and those along the western shoreline had sparse or no vegetation with low species diversity.

iii) Several species present in the main Bay in 1977 were not encountered or present in only very limited numbers in the 1983 survey, namely Ceratophyllum demersum and P. richardsonii.

iv) A significant reduction in SAV abundance is apparent at stations 2 and 8 between 1975 and 1977. (These are the only 2 stations representing the open water portion of the Bay that were vegetated in 1975.).

v) M. spicatum is notably absent as a dominant species.

While the reliability of some of the taxanomic data in this report is questionable, it does demonstrate that by late August of 1977, much of the extensive beds of SAV in the Bay had disappeared, although the effect was restricted to the open water zone and not the protected backwaters where M. spicatum had not flourished.

4.2 EXISTING SAV COMMUNITIES

4.2.1 Sampling Method

The distribution and abundance of SAV in the Bay was determined using a drag sampler towed behind a motor boat. The sampler was specially designed and constructed to uproot the stalks of SAV about 3-6 cm below the sediment surface. In this way, both upright-stalked species such as H. dubia, M. spicatum and P. pectinatus were collected in addition to species like V. americana, Chara spp. and Najas spp. The sampler was dragged over a measured distance, then raised to the surface and all SAV in the wire mesh collector deposited in sample bags. Subsequently, the number of rooted stalks by species were enumerated and dry weight biomass by species was measured (Table 3). The efficiency of the sampler was checked on several occasions. After a pass had been made with the drag, divers traced the drag route. Due to the highly turbid condition of the water direct visual exmination was not possible, but careful manual searches produced no remnant stalks of SAV. In fact, the drag scoured about 4-6 cm of material off the top of the sediments forming a shallow trench. This suggested that virtually all SAV in the path of the drag was collected. Occassionally in deeper waters, fragments of SAV would escape from the mesh collector. Where possible these were collected from the surface but care was necessary not to include free-floating specimens drifting past from other lcations. The biomass lost due to escape from the collector is not expected to exceed 5 % of the total sample collected.

SAV sampling stations were selected i) where stalks were apparent from the surface, ii) where historically SAV had been noted or iii) to provide coverage of a major habitat type (Figure 17). The sampling design was intended to characterize the SAV communities in terms of species composition, standing biomass and habitat conditions, the sampling was not intended to provide comprehensive coverage of all SAV stands in the Bay or to delineate precisely the limits of individual beds. While this information would be useful, it was beyond the scope of this study.

4.2.2 Distribution and Abundance

The current distribution of SAV in the Bay closely matches that mapped from the 1978 photographs (Figure 18). The majority of the SAV is located in the southwest and southeast corners of the Bay with scattered stands distributed along either shore in protected bays or in water depths over 1.6 m. Little growth was observed in water depths greater than 1.9 - 2.0 m with the exception of scattered stands of P. pectinatus. This species was observed growing in water

TABLE 3 STANDING BIOMASS - AUGUST 1983

Sample Number	Water Depth (m)	Community Type	Length of Drag (m)	Number of stalks/biomass dry wt.g. per Drag Haul						
				Vallisneria	Heteranthera	Myriophyllum	Chara	Potamogeton pectinatus	Potamogeton crispus	Najas minor	Other
1	1.3	H-M	10	--	1/0.25	6/6.70	--	--	--	2/0.06	--
2	1.5	H	10	--	32/115.01	1/0.014	--	--	--	--	--
3	1.5	H-M	10	--	4/6.42	1/0.13	--	--	--	--	--
4	2.0	H-M	10	--	3/2.35	--	--	--	--	--	--
5	2.05	H-M	10	--	--	--	--	--	--	--	--
6	1.9	H-M	10	--	57/112.28	2/0.75	--	--	--	--	--
7	1.8	H-M	10	--	--	--	--	--	--	--	--
8	1.9	H-M	10	--	18/15.0	3/1.53	--	--	--	--	--
9	2.6	H-M	10	--	--	--	--	--	--	--	--
10	2.1	H-M	10	--	--	--	--	--	--	--	--
11	2.1	M-N	10	--	--	10/24.02	--	--	--	--	--
12	1.1	M-N	10	--	--	4/0.38	--	--	--	5/0.07	--
13	0.95	V-N	10	5/1.24	--	--	--	--	--	6/0.05	--
14	1.0	V-N	20	31/11.15	--	--	--	--	--	2/0.12	U 4/0.30
15	0.95	V-N	20	--	--	--	--	--	--	--	--
16	1.0	V-N	20	1/0.25	--	1/0.04	--	--	--	12/0.34	P03/0.10
17	1.3	M-N	20	--	--	4/0.43	--	--	--	5/0.09	NF1/0.01
18	1.3	M-N	20	--	--	--	--	--	--	--	--
19	2.0	V-C	20	1/0.12	--	--	--	--	--	--	--
20	1.6	V-H	30	--	1/0.65	--	--	--	--	--	NF1/0.03
21	1.5	V-H	30	4/16.14	1/1.20	--	*/0.32	--	--	--	--
22	1.55	V-H	30	103/24.67	20/5.23	6/0.82	*/0.85	--	--	7/0.11	E4/0.24
23	1.4	M-N	30	--	--	50/20.93	*/0.03	--	--	1/0.01	E4/0.05
24	1.8	V-N	30	1/0.17	--	--	--	--	--	7/0.49	P02/0.48 SF1/0.49
25	0.9	V-C	30	24/1.13	--	--	*/0.09	--	--	--	--
26	0.9	V-C	30	12/3.23	--	--	*/0.20	--	3/4.20	--	--
27	0.9	V-C	30	1/0.99	--	--	*/0.23	1/0.14	--	1/0.06	--
28	1.1	V-C	30	3/0.19	--	--	*/0.02	--	--	--	--
29	1.2	V-N	30	--	--	--	--	--	--	2/0.08	--
30	1.4	V-N	30	--	--	--	--	--	--	--	--
31	1.1	V-N	30	--	--	--	--	--	--	--	--
32	1.45	V-N	30	--	--	--	--	--	--	--	--
33	1.8	M-N	30	--	--	2/1.05	--	--	--	--	--
34	1.8	M-N	30	--	--	--	--	--	--	--	--
35	1.1	M-N	30	--	--	--	--	--	--	--	--
36	1.3	M-N	30	--	--	--	--	--	--	--	--
37	2.0	M-N	30	--	--	--	--	--	--	--	--

Sample Number	Water Depth (m)	Community Type	Length of Drag (m)	Number of stalks/biomass dry wt.g. per Drag Haul							
				Vallisneria	Heteranthera	Myriophyllum	Chara	Potamogeton pectinatus	Potamogeton crispus	Najas minor	Other
38	2.0	P	30	--	--	--	--	5/9.58	--	--	--
39	1.4	P	30	--	--	--	--	--	--	--	--
40	0.95	P	30	--	--	--	--	--	--	--	--
41	1.2	P	30	--	--	--	--	--	--	--	--
42	1.1	M-N	30	--	--	--	--	--	--	9/0.13	--
43	1.95	H-M	30	--	6/4.52	2/0.16	--	--	--	3/0.04	--
44	2.05	H-M	30	--	15/17.95	4/2.59	--	--	--	--	E1/0.02
45	2.35	P	30	--	--	1/0.15	--	28/54.35	--	1/0.01	--
46	2.75	P	30	--	--	--	--	1/0.17	--	--	--
47	2.35	P	30	--	--	--	--	--	--	--	--
48	2.1	M-M	30	--	1/0.15	1/0.03	--	--	--	--	--
49	1.6	H-M	30	4/16.7	76/114.80	2/1.13	--	1/0.03	--	1/0.04	--
50	2.0	H-M	30	--	15/10.69	--	--	--	--	--	--
51	2.0	H-M	30	--	33/49.4	2/1.62	--	--	--	--	--
52	2.05	H-M	30	--	1/0.44	1/0.16	--	--	--	--	--
53	0.95	H-M	30	--	2/2.13	3/2.02	--	--	--	--	M*/48.58
54	0.9	H-M	30	--	1/2.62	11/23.14	--	--	--	--	NF1/0.08
55	3.1	H-M	30	--	--	--	--	--	--	--	--
56	3.2	H-M	30	--	--	--	--	--	--	--	--
57	1.35	V/H	30	34/22.15	1/1.45	--	--	--	--	--	--
58	1.1	V/H	10	56/50.10	51/432.49	6/6.44	*/273.77	--	22/27.37	--	NF1/.51 E1/.51
59	1.1	V/H	20	25/2.88	1/2.42	1/0.48	*/32.66	--	42/8.60	--	E6/0.83 NF22/5.5

* Chara and moss spp. has no roots and therefore no definable stalk.

E Elodea canadensis
PO Polygonum natans
SF Sparganium fluctuans or Juncus
U Utricularia
M moss spp.
NF Najas flexilis
P Potamogeton pectinatus
H Heteranthera dubia
V Vallisneria americana
C Chara
N Najas minor
M Myriophyllum spicatum

Note: Samples go from 1-59. Those missing from the table had nothing in the catch.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

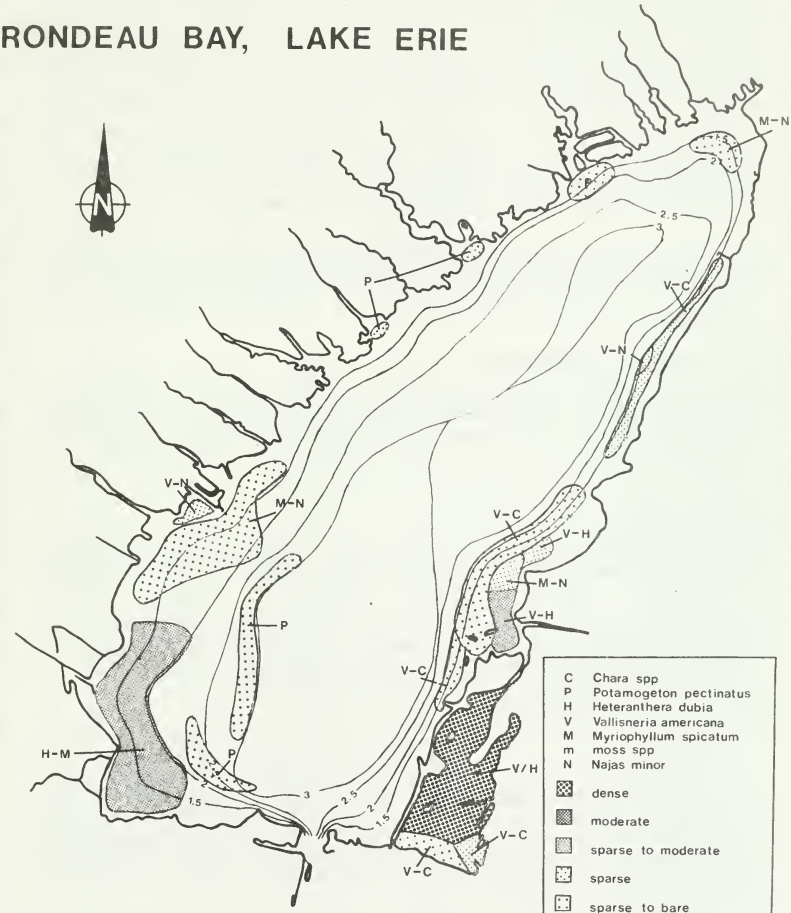
SCALE 1:50,000

Depth contours meters

JEHanna Associates Inc.	VEGETATION SAMPLE STATIONS	FIG. 17

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours: meters

JEHanna Associates Inc.

VEGETATION DISTRIBUTION
AUGUST 1983

FIG. 18

depths between 2.5 and 3.0 m along the south western shore. The distribution of these stands was quite patchy and each stand was very sparse with between 3-20 rooted stalks per stand.

The protected bay in the southeast corner supported the highest diversity, density and continuity of SAV; in fact, motor boat traffic was difficult due to entanglement of the prop. The southwest corner also supported a moderate diversity of SAV but standing biomass was much less than at the preceeding location. The backwater areas along the eastshore in the marsh were not sampled but visual observations suggest that they are comparable in diversity but less luxuriant than the southeast sector.

SAV in the drainage ditches proper along the western shore was generally more diverse and abundant than in the Bay. The plants were concentrated along the edges of the ditches normally in water less than 1.0 m. Floating emergents and submergent species were common.

4.2.3 Community Descriptions

This section characterizes SAV communitites in terms of species association and dominance, structural features and habitat affinities. Particular attention has been given to characteristics which have potential significance to restoration techniques or strategies.

4.2.3.1 Community 1: H - M

This community is dominated by H. dubia with M. spicatum being the major subdominant species. Other species present include V. americana, Najas minor, P. crispus and P. pectinatus. The community is restricted to the southwest section of Bay and occurs between 1.3 and 2.0 m of water on silt or sandy silt. The average density was 0.76 stalks per sq.m (spsm) and 1.30 g per sq.m (gpsm) of H. dubia and 0.9 spsm and 1.60 gpsm for all species combined.

The plants were distributed in dense patches ranging in diameter from 1 m to 2.5 m with 5 to 30 m between patches. The distribution of M. spicatum was closely associated with the H. dubia clumps and these plants were generally rooted directly in the clumps. Several stands of V. americana were present but this species was restricted to these few sites and was not found dispersed elsewhere in the community. P. crispus and P. pectinatus were generally found along the deeper fringes of the community and they occurred as disperse individual specimens.

4.2.3.2 Community 2: M - N

The dominant species in this community is M. spicatum with N. minor occurring as an infrequent subdominant. The community is broadly distributed along the western shoreline but is very patchy and each stand generally consists of only a small number of plants. It occurs in water depths between 1.0 and 2.2 m on silt or clay sediments and less frequently on sandy organics.

Stalk densities are in the order of 0.35 spsm with a corresponding biomass of 0.23 gpsm. N. minor averages about $8.5*10^{-4}$ gpsm in this community type and occurs most frequently in water depths less than 1.5 m.

The distribution of M. spicatum stalks is quite dispersed within a stand; normally each clump of 2 or 3 stalks is separated from the next by 20 to 60 m.

4.2.3.3 Community 3: V / H

Two species are codominant in this community, namely V. americana and H. dubia. A number of other species are also present including M. spicatum, N. minor, Chara, and P. crispus. The community is restricted to the protected southeast section of the Bay in water depths between 1.0 and 1.5 m on sandy organic substrate.

This community type had the highest stalks and biomass densities in addition to the highest species diversity. Average stalk and biomass densities for V. americana, H. dubia and all species combined were 1.92 spsm and 7.25 gpsm, 0.88 spsm and 7.27 gpsm and 4.48 spsm and 14.47 gpsm respectively.

As the substrate becomes increasingly sandy toward the Lake Erie barrier sand bar, the stalk and biomass density decreases. In addition, species diversity decreases and the community shifts to Type 4: V-C. In the shallower backwater section near the cattail marsh, Zizania aquatica becomes dominant.

4.2.3.4 Community 4: V - C

V. americana dominates this type with Chara forming a discontinuous bottom mat. This community occurs on both sandy organics and sand substrates in water depths between 0.5 and 1.3 m. The community occurs along the edge of the Lake Erie basin sand bar east of the harbour entrance and behind the submerged beach ridges on the southeast shore of the Bay. Density varies as a function of substrate type with the highest biomass values recorded on the sandy organics and the lowest on the clear sand. The average densitites for the community are 0.26 spsm and 0.03 gpsm of V. americana and 0.27 spsm and 0.06 gpsm in total.

4.2.3.5 Community 5: P

Stands of P. pectinatus normally were either monospecific or had a low incidence of either P. crispus or M. spicatum. This community occurs in two distinct habitats. In open water conditions, it is found in water depths between 2.0 m and 3.0 m along the western shore on silty organic substrate. Average densities are 0.15 spsm and 0.29 gpsm with the plants occurring in an extremely dispersed pattern. Each grouping of plants consists of 3 and 20 stalks and may be separated from the next patch by 50 to 200 m.

The other habitat type in which this community occurs is in water depths of between 0.2 and 0.4 m on silty substrates at the mouths of several drainage ditches. This community type could not be sampled but visual estimates indicated densities in the order of 0.10 spsm. In this habitat, the stands were monospecific and often extended several hundred meters up the ditches where suitable habitat conditions were available.

4.2.3.6 Community 6: V - N

Communities 4 and 6 are similar in that V. americana is the dominant species and they are restricted to relatively shallow water (ie less than 1.5 m). The major differences between the two are the primary substrate type and the subdominant species association. The V - N community occurs on silty clay and silty sand substrates. Average densities of V. americana are in the order of 0.24 spsm and 0.08 gpsm and 0.48 spsm and 0.1 gpsm for all species combined. The plants tend to occur in scattered patches and the density of the patches themselves appears highly variable. N. minor occurs sporadically throughout.

4.2.3.7 Community 7: V - H

This type is similar to communities 4 and 6 in that V. americana is the dominant species; however, H. dubia is the primary subdominant and the community is found on substrates intermediate between the relatively clean sand which supports type V - C and the richer sites which support community V/H.

The V - H type occurs in water depths of about 1.5 - 1.8 m and has a moderately high density of V. americana, 0.89 spsm and 0.34 gpsm and for all species combined, 1.23 spsm and 0.42 gpsm. The distribution of SAV is quite patchy but growth is quite dense where the patches occur, namely in the swales between the submerged beach ridges along the east shore.

Species diversity was quite high in this community with Chara and N. minor occurring as regular constituents of the bottom vegetation layer. Elodea canadensis also was encountered. M. spicatum was associated with the patches of V. americana and was not seen growing separately in this community.

4.3 TEMPORAL TRENDS

Two types of temporal trends are considered, namely shifts in species dominance/composition and trends in the distribution and abundance of SAV in the Bay generally.

4.3.1 Species Trends

The most dramatic trend evident in the Bay has been the demise of M. spicatum from being an aggressive invading species forming dense monospecific stands across over 40 % of the Bay to its current status as an infrequent subdominant in some communities. It is the dominant species in community 2: M-N, but, this type is sparsely distributed and has low biomass densities. There was no evidence from the 1983 survey to suggest that this species might start into another invasion cycle and might reach densities comparable to those recorded in the 1960's and 1970's.

The only other basis of assessing trends in species composition is the records contained in the Rondeau Park Draft Master Plan report (anon., n.d.). It is indicated that P. vaginatus (c.f. H. dubia) was present at the northern end of the Bay. During the 1983, H. dubia was restricted to the extreme southern section of the Bay suggesting that the distribution of this species may be contracting.

Similarly, Ceratophyllum demersum was observed in the southwest and southeast corners of the Bay in 1977. This species was not observed at any open water station during the 1983 survey, although Ministry of the Environment staff reported seeing a large bed in the deep open water portion of the northern basin (J.Westwood, per. comm.). The preferred habitat of C. demersum is quiet waters with low to moderate turbidity. It is therefore possible that the specimens observed in 1977 were remnants of stands that had occurred when milfoil was abundant in the Bay and that the species has since declined in abundance and distribution.

P. crispus is the only species which may have increased in abundance since 1977; notably this species was not mentioned in the 1977 records. It is an aggressive exotic with some colonization characteristics common to M. spicatum. It has become a nuisance species in other inland waters in North America but is less conflicting with recreational activities compared to M. spicatum since P. crispus dies back to a large extent by mid to late July.

In conclusion, adequate historical records are not available to assess the status of individual SAV species and community composition. There does appear to have been some reductions in native species of SAV since 1977 and P. crispus may have recently become common in the Bay.

4.3.2 Distribution and Abundance Trends

Precise delineations of community boundaries were not undertaken as part of this study. In addition, the community boundaries derived from aerial photographs depict only major concentrations of SAV that are visible and near the water surface. Accordingly, it is not possible to state definitively whether SAV beds are expanding or contracting or what the rate of change might be. The current distribution of SAV corresponds quite well to that evident from the 1978 photographs. This suggests that the beds which survived the milfoil collapse have been able to maintain growth, to some extent, at these sites for at least six growing seasons.

Of particular importance in evaluating alternative management techniques and strategies is to determine whether the existing stands of SAV are expanding and at what rate. If natural regeneration is to be considered a viable restoration option, any prediction of the rate of recovery is highly dependent on such data. Based on the available data, it is concluded that over the six year period from 1978 to 1983, expansion of SAV communities has been quite limited if it has occurred at all.

5 SEDIMENTS

This section describes the results of the sediment sampling and analysis undertaken in the Bay.

5.1 SAMPLING AND ANALYSIS METHODS

The sediment sampling program consisted of running a series of transects across the Bay and at other strategic points (Figure 19). In addition, samples were taken across the streambed for each major drainage ditch inflowing to the Bay.

A sediment corer fixed with plexiglass tubing (inside diameter 6.4 cm) and a rubber plunger was used to collect the samples. This instrument permitted intact cores of sediment to be removed, visually examined in the tube and collected either intact or in sections. An extension on the corer permitted samples to be collected in water depths up to 4 m.

At each sample point, the precise location was fixed through compass bearing triangulation. Water depth was recorded and a sediment core ranging from 20-50 cm in length was obtained. Layering and physical characteristics of the core were recorded. Relatively homogeneous cores were sampled as a whole but well stratified heterogenous cores were sectioned and collected separately.

The samples were analyzed for particle size distribution, total phosphorus, and total organic content. The method described by Mayer and Williams (1981) was employed in the analysis of total phosphorus.

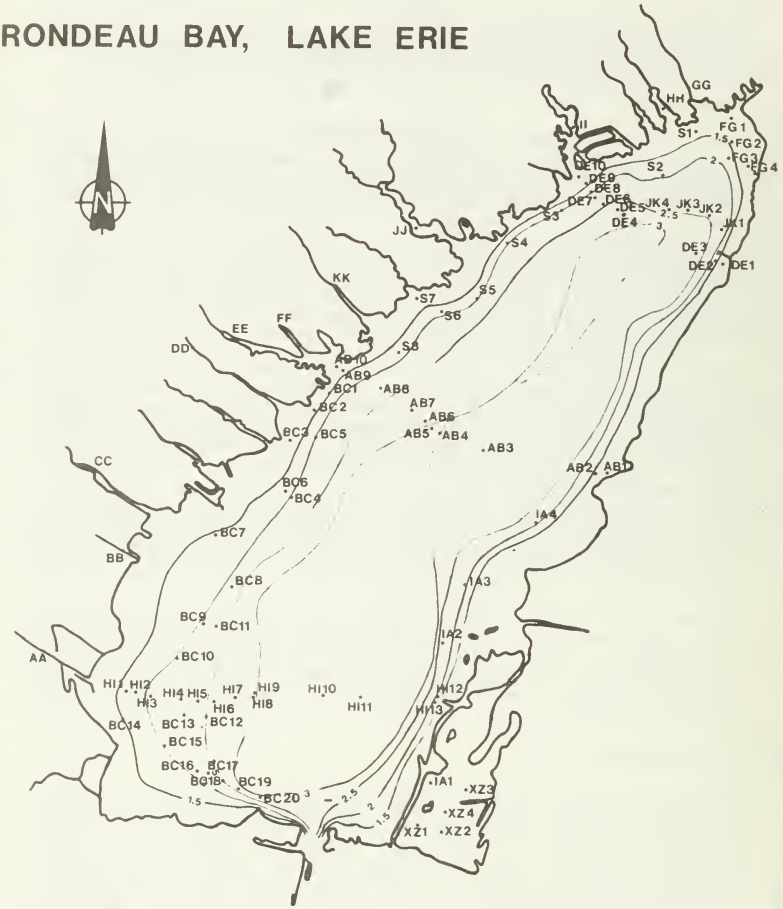
A series of representative cores were collected from each of the major sediment groups found in the Bay. These samples were retained for reference and for illustration purposes. In addition, grab samples of sediment were collected using a ponnar dredge; this material was used for the growth experiments (see Section 5.3).

5.2 SEDIMENTATION HISTORY

The stratigraphic pattern of sediments can be the most definitive and reliable record of depositional history. This study focussed primarily on recent depositional events; a drilling survey by Environment Canada has analysed sediment deposition over a much longer period (anon., n.d.) Some general observations can be made based on the sediment stratigraphy recorded during the field sampling program of the current study and other information available concerning the Bay.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours: meters

JEHanna Associates Inc.	SEDIMENT SAMPLE STATIONS	FIG. 19

i) A large segment of the western and southwestern shoreline of the Bay out to water depths of 2.5 to 2.8 m is underlain by fibrous organic peat (about rank 8 on the Von Post humus scale). This type of peat appears to be composed primarily of coarse marsh vegetation in particular Typha spp. The formation is typical of shallow water marshes (ie water depths less than 1 m) and strongly suggests that historically (ie several thousand years ago) water levels were much lower than at present. During this period much of the Bay must have been covered by fairly extensive marshlands.

ii) The strata overlying the peat vary in depth and physical composition. Fine to medium sand with only a small percentage of silt or clay (see Figure 20 and Appendix B provides particle distribution curves for representative samples) is common along parts of the southern littoral zone of the Bay. The depth of the overlying sand varies between 5 and 20 cm and in some cases particularly toward the fringe of the peat formation, alternating layers of peat and sand are encountered. This sand likely originated from Lake Erie entering the Bay through the harbour mouth or was deposited prior to the formation of the Erieau spit.

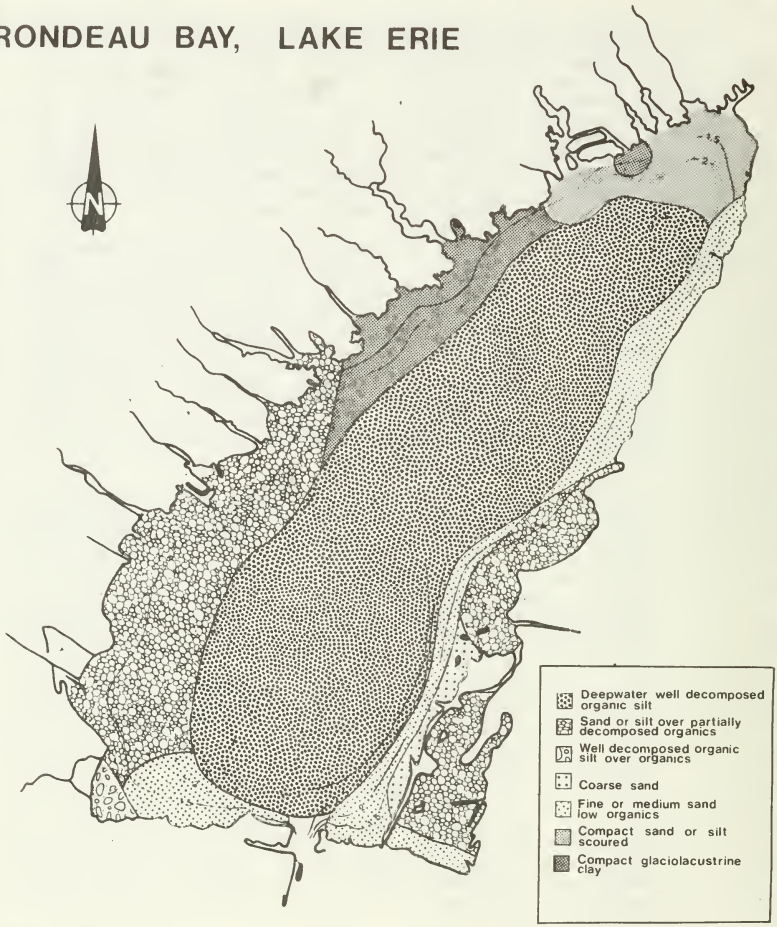
iii) The silt and clay fraction of the overlying stratum increases substantially toward the north although bars of fine sand are common along the shoreline at depths of 0.8 to 1.2 m. The silt strata vary in depth up to 15 cm with a characteristic flocculent surface layer of 2 to 4 cm over a more compact layer. The underlying peat is replaced by lacustrine clays just north of Shrewsbury. Underlying peat deposits are common immediately adjacent to the shoreline and in the beds of drainage ditches.

iv) The sediments along the northwestern shoreline are composed of a discontinuous flocculent silt layer from 0 to 6 cm overlying highly compact glacio-lacustrine blue clay. The depth of the silt layer increases at the mouths of drainage ditches and bars of fine sand may be present in the wave-washed zone.

v) Virtually all of the eastern side of the Bay consists of fine to coarse sands out to about the 2.4 m contour. A series of submerged sand bars run parallel to the shoreline and peat deposits are common in the swales between the ridges.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

Depth contours meters

JEHanna Associates Inc. | SURFICIAL SEDIMENTS | FIG. 20

vi) In the central basins of the Bay at depths greater than about 2.4 to 2.6 m, a continuous layer of organic silty ooze is present that is greater than 1 m in most locations. Up to 15% of this sediment consists of organic material.

These observations lead to the following conclusions.

i) The majority of the incoming sediments to the Bay are deposited either in the mouths of the drainage ditches, in the deeper basins, or are exported to Lake Erie. The littoral zone out to about 2.2 to 2.4 m appears to be periodically scoured by wave action.

ii) The lack of layering and the fluid nature of the deep water sediments suggests a deep active mixing zone and that definitive estimates of recent changes (ie over 10-20 years) in sediment loads to the Bay will be difficult to derive from sediment stratigraphy.

iii) Historically, water levels were up to 2 m less than at present and cattail marshes covered much of the western side of the Bay.

Two other significant factors confound the interpretation of the recent depositional history of Rondeau Bay. The most important is the dramatic changes in SAV abundance which have occurred over the past 20 to 25 years. When dense milfoil beds covered the Bay, water clarity was greater than at the present time (see Section 3.1); this is likely partially due to increased settling rates of suspended solids and lack of resuspension due to wave attenuation. When the milfoil beds died out, the sediment which had accumulated was exposed to resuspension and it is likely that a significant relocation of the material took place. Decreased rates of sediment deposition in the deepwater zone during the milfoil invasion and rapidly increasing rates following may not relate at all to sediment yield from the watershed but instead to sediment redistribution in the Bay.

The second confounding factor is the deposition from and export to Lake Erie of sediments. Unlike most contained inland lake where water flows through the outlet in only one direction, the habour entrance to Rondeau is some times an inlet and source of sediment and at other times an outlet. The complex hydrological relationship between Rondeau Bay and Lake Erie and its dependance on various water level cycles (see Section 2.3) causes sediment deposition to be cotrolled by many factors other than simply sediment yield from the watershed. These factors are of particular significance when short duration analyses are made. It is reported though, that historical long-term average sediment deposition rates in the deep water zone of the Bay are in the order of "... 2.6 mm per year which is close to the average for all of Lake Erie". (anon., n.d.).

5.3 EXISTING SEDIMENT CHARACTERISTICS

Seven major sediment types were identified on the basis of grain size, organic content and stratigraphy. The boundaries of these types correspond, in a general sense, to the sediment composition map in the Rondeau Park Draft Master Plan (anon., n.d.) and the report by Berst (1950).

5.3.1 Particle Size Distribution and Organic Content

The particle sizes of the sediment types sampled varied from fine-grained clays to coarse gravel and sand. The majority of the Bay is covered by an organic silty clay. Total organic content in these samples ranged between 6 and 16 % (Table 4). This sediment lacked any distinctive layering or differentiation with depth for up to 0.75 m. The material was quite amorphorous and did not exhibit any substantial cohesive structure when collected. No strong odours of hydrogen sulphide were detected to suggest strong anaerobic conditions. This sediment type begins at between 2.4 and 2.8 m and extends across all deepwater portions of the Bay.

The next most common sediment type is sand and/or silt overlying partially decomposed organics. The underlying layer is essentially all organics. The organic content of the overlying silt and sand varies according to the deposition environment and degree of mixing with the peat layer. It is normally less than 10% and may be as low as 1%. The grain size of the inorganic component is determined by proximity to silt sources (ie drainage ditches) and wave exposure; finer sediments are found near the drainage ditches in protected locations.

Much of the northwestern shoreline is underlain by compact lacustrine clays or scoured silty sand. The clay has a low organic content in the range of 1%. Due to its compact and cohesive nature, this sediment type is quite resistant to erosion although a small but significant amount of fine suspended material could be contributed during heavy wave action. The clay is a bluish colour with small flecks of reddish-brown iron oxide.

The silty sand is fairly compact and no layering or differentiation with depth is evident up to 0.4 m. The organic content of the sediment varies somewhat but is generally in the order of a 1 to 2%.

The eastern and southern littoral zone of the Bay is underlain by sand of varying particle sizes. The finest sands are found along the south and east shores at depths around 2 m and along protected sections of the eastern shore. The wave-washed zone is characterized by coarse sand and gravel. The organic content in these sediments is generally

TABLE 4 RESULTS OF SEDIMENT ANALYSIS

Sample	Sediment description	LOI (organic content)%	Phosphorus (mg/g)
H-I 9	deepwater, well decomposed organic silt (A)	14.418	24.8
A-B 6	deepwater, well decomposed organic silt (A)	6.153	20.2
H-I 6	partially decomposed organics with fine sand (B)	7.280	30.2
B-C 6	compact sand or silt, scoured (D_1)	1.830	12.2
A-B 4	deepwater, well decomposed organic silt (A)	16.557	19.6
H-I 10	deepwater, well decomposed organic silt (A)	14.767	24.9
GG 2	floc over well decomposed organic silt (A_F)	42.405	40.7
S 6	compact glaciolacustrine clay (D_2)	1.308	16.3
B-C 20	fine or medium sand, low organics (C_1)	7.118	15.8
KK 1	floc over compact glaciolacustrine clay (D_{2F})	5.476	22.8
II 1	floc over sandy clay (D_{IF})	14.951	33.7
S 4	compact glaciolacustrine clay (D_2)	2.650	11.3
B-C 2	compact sand or silt, scoured (D_1)	1.643	14.2
H-I 13	coarse sand (C_2)	0.132	10.0
I-A 4	coarse sand (C_2)	0.135	4.5
I-A 2	partially decomposed organics with fine sand (B)	0.594	14.0

low, particularly where wave action is pronounced (ie less than 1%). Slightly higher organic content occurs in the deeper zones with values up to 2 or 3%.

The last major sediment type found in the Bay is also characteristic of the drainage ditch sediments, that is silty organics overlying partially decomposed organics. These sediments have a high portion of fines that are readily suspendable with turbulence. In addition, organic content ranges from 14% up to 40%.

5.3.2 Phosphorus Content

Total phosphorus content in the sediments ranged from a low of 4.5 ppm in coarse sand to a high of 40.7 ppm in fine-grained sediments sampled in the drainage ditches. Several general patterns in terms of nutrient content are apparent.

i) Phosphorus concentrations are highest in the sediment being contributed by the drainage ditches (ie average measured concentration 32.4 mg/g); whereas, the lowest concentrations are in the wave-washed sediments along the east shore (average measured concentration 9.5 mg/g). The fine-grained deepwater sediments were intermediate with an average concentration of 23.9 mg/g.

ii) Sediments with high organic content appear generally to have higher phosphorus concentrations.

iii) The finer-grained sediments have higher phosphorus concentrations. This likely reflects adsorbed phosphorus particles.

Generally, the phosphorus concentrations in the sediments are quite high and adequate to support SAV growth. Considering the phosphorus concentrations in the water (see Section 3.2.2) and the sediments, nutrient availability is not likely limiting SAV growth.

5.3.3 Pesticides

In 1977 and on several occasions in 1983 staff of the Ontario Ministry of the Environment collected sediment samples from the Bay and inflowing drainage ditches and submitted them for pesticide analyses. All major herbicides used by the agricultural community in the watershed were tested and in all cases, concentrations were below the detection limits of the analytical procedures.

These results agree with those obtained in the Chesapeake Bay studies (Meano et al, 1983; Kemp, et al, 1982; Zahnow and Rigglemon, 1980; Wu, 1980). It was found that most agricultural herbicides degrade rapidly in sediments and concentrations are normally quite low.

The analysis results confirm field observations which indicate that the mouths of the drainage ditches support relatively extensive SAV growth. If herbicides were limiting SAV, concentrations would be highest in these drains and therefore effects would be most severe. It is concluded therefore that herbicides in the sediments are not currently limiting SAV growth and distribution significantly.

5.4 SEDIMENTS SOURCES

An objective of the sediment survey was to determine through the characteristics of the suspended and bed load of inflowing watercourses, principal sources of sediment in the watershed. The results of the survey confirmed expectations in terms of variations between watercourses. Namely, a high degree of consistency between sediment samples from the various watersheds was observed. This result was expected since the soil groups in the watershed tend to run perpendicular to the principle drainage pattern; as a result, most streams intersect the same soil types.

Several features of the stream sediments were noteworthy.

i) A flocculent layer of silt varying in depth from 5 to 25 cm was noted in all the drainage ditches. This material was readily suspendable in water. In many cases, the underlying silt was only slightly more compact and appeared to be readily erodable under high flow conditions. These observations suggest that a significant supply of suspendable material is present in the drainage channels. The rate at which this source would be depleted without further additions from upstream is difficult to ascertain but a minimum period of several years is estimated.

ii) The surprisingly high organic content in the stream sediments confirms observations made in the Master Erosion Control Plan that much of the humus layer in the agricultural fields was being depleted and eroded (Ecologistics Ltd., 1983).

No specific conclusions can be made concerning specific sediment sources in the watershed. However, clearly a large supply of suspendable fine-particle sediments is present in the drainage ditches.

5.5 WAVE CLIMATE

Wave action influences the ecology of Rondeau Bay by two primary means. First, resuspension of sediments due to wave action is an important determinant of suspended solids concentrations and associated turbidity. As discussed in Sections 4 and 6, turbidity is a primary limiting factor for SAV growth.

The second effect of waves on SAV is more direct; wave action has been shown to cause physical damage to SAV stalks and leaves and during severe events can lead to uprooting of plants (Sculthorpe, 1967). Spence (1967) demonstrated that P. pectinatus grew much more robustly in protected as opposed to exposed sites; damage was particularly severe in the wave break zone.

The first effect (resuspension of sediments) occurs under moderate to severe wave conditions and is related to the frequency and intensity of wave events. The principle factors influencing direct damage to SAV are less well understood but severe storms during the mid to late part of the growing season are expected to be most significant.

To gain an appreciation of the significance of waves on sediment resuspension and SAV distibution and abundance, an analysis of the wave climate in the Bay was undertaken. Average wave conditions were characterized using wind speed, direction and frequency records for Windsor Airport (Atmospheric Environment Services, 1983) and nomographs designed to predict wave heights given various water depths, fetches and wind speeds (anon., 1977). Figures 21 to 23 illustrate wind roses for April/May, June/July and August/September respectively. These figures clearly demonstrate that winds from the west and south sectors are increasingly predominant over the summer months and that the strongest average winds are also from these directions.

Wind data for two key periods in the growing season for SAV, May/June and July/August, have been used to estimate average significant wave heights from the six most frequent wind directions (Table 5). This analysis clearly shows that the eastern and northern shores of Rondeau experience the most frequent and strongest wave action. Average wave heights are relatively small (ie less than 0.4m) due to the shallow depths of the Bay. However, wave reflection and the gently sloping bottom can combine to produce a "chop" condition with significant wave turbulence, particularly in the northern sector.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

SCALE 1:50,000

WIND SPEED: KM/HR

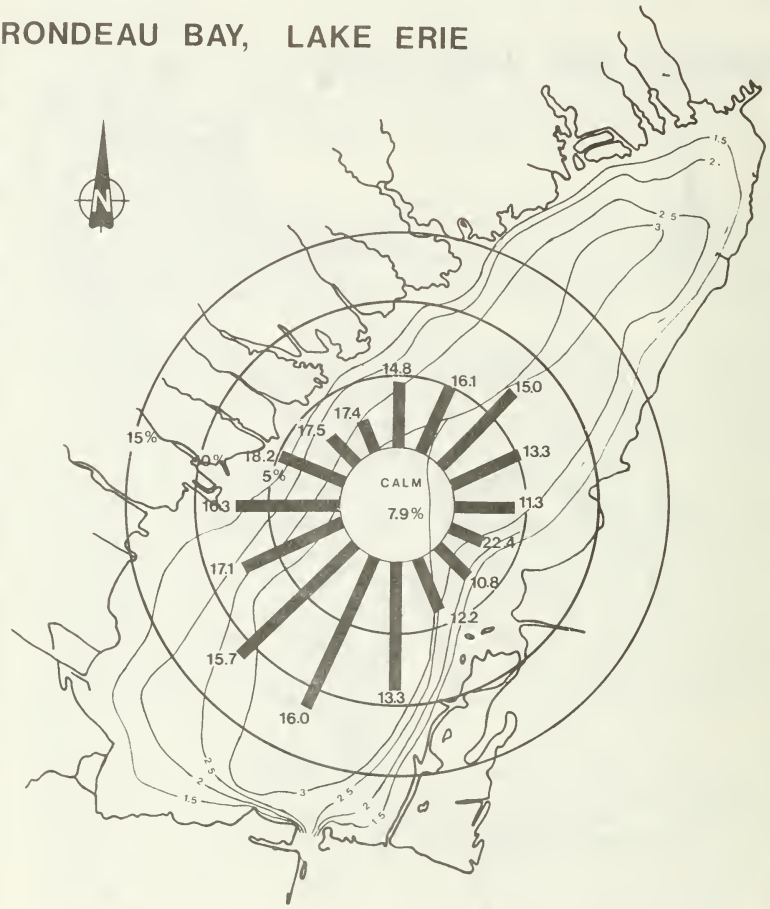
Depth contours meters

SOURCE: ENVIRONMENT CANADA, WINDSOR AIRPORT

JEHanna Associates Inc.	WIND ROSE APRIL – MAY	FIG. 21

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

WIND SPEED: KM/HR

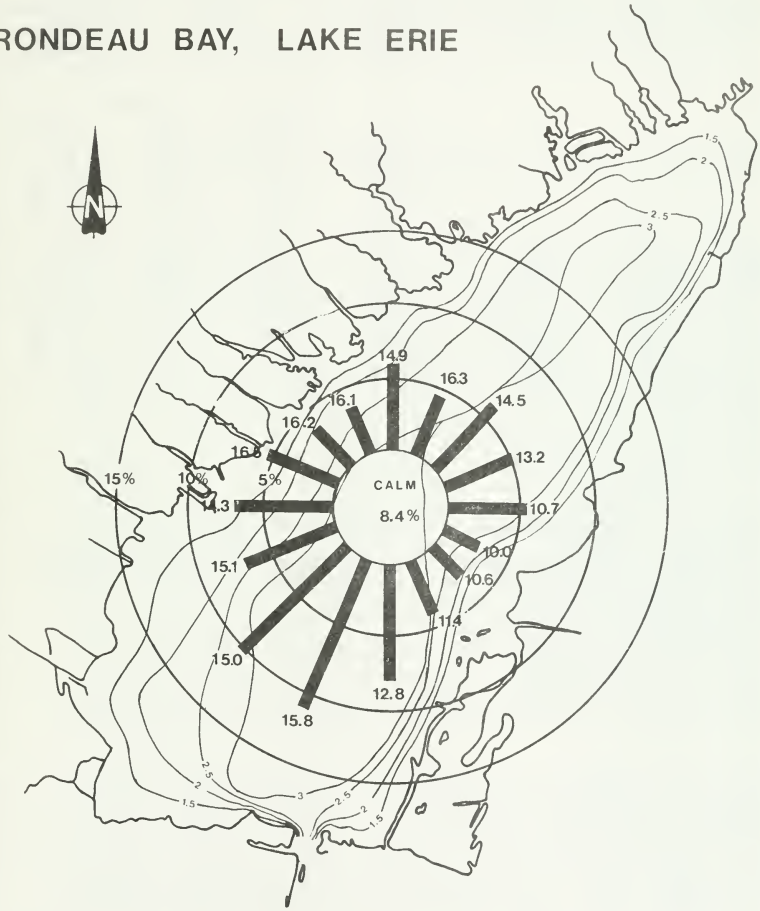
Depth contours meters

SOURCE: ENVIRONMENT CANADA, WINDSOR AIRPORT

JEHanna Associates Inc.	WIND ROSE JUNE–JULY	FIG. 22

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



SCALE 1:50,000

WIND SPEED: KM/HR

Depth contours - meters

SOURCE ENVIRONMENT CANADA, WINDSOR AIRPORT

JEHanna Associates Inc.	WIND ROSE AUGUST–SEPTEMBER	FIG. 23

TABLE 5 WAVE FREQUENCY AND HEIGHT

Season	Wind* Direction	Frequency (%)	Average Wind Speed (km/hr)	Fetch. (km) max.	Fetch. (km) av.	Average Wave Height (m)
May/ June	SSW	10.7	18.3	8.9	7.25	0.21
	SW	9.5	17.4	10.5	8.75	0.23
	S	8.4	15.1	7.25	5.5	0.20
	NE	8.2	16.5	10.5	8.75	0.23
	W	6.9	18.8	5.0	3.0	0.18
	WSW	6.6	19.7	7.0	5.0	0.20
July/ August	SW	11.7	14.7	10.5	8.75	0.20
	SSW	10.9	15.1	8.9	7.25	0.21
	S	8.5	12.2	7.25	5.5	0.17
	WSW	7.5	15.5	7.0	5.0	0.18
	W	7.2	14.3	5.0	3.0	0.15
	NE	6.9	14.3	10.5	8.75	0.20

* Note: During July/August the frequency of calm is 8.8%.
During May/June the frequency of calm is 5.9 %.

SOURCE: U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER, 1977.

This analysis suggests that during the May/June period only one out of every 17 days can be expected to be calm and the average waves are in the order of 0.23 m from the southwest quarter. A similar condition exists for July/August except that one out of every 11 days can be expected to be calm and average wind speeds are less.

5.5.1 Sediment Resuspension

Resuspension depends on the depth to the bottom, particle size, compaction and cohesion of the sediments and the water/sediment interface shear force caused by water turbulence.

No widely-tested and accepted method of predicting sediment resuspension by waves for small inland water bodies such as Rondeau Bay was found. In principle, this type of analysis would require extensive detailed input data to parameterize the model. For example inputs relating to deposition rates, sediment characteristics, bottom contours and wind and wave climate would be required. Such an analysis could provide some insight into the dynamics of sediment resuspension through wave action but this detailed level of analysis would have exceeded the current understanding of the overall sediment transport and deposition environment of the watershed and the Bay. In addition, management techniques to control wave action are expensive and infeasible on an extensive scale for a water body the size of Rondeau Bay.

A simple experiment was conducted in the field to provide some fundamental understanding and evidence of the significance of wave resuspension of sediments. On the morning of August 20, 1983, a light SSW wind (ie less than 5 km/hr) was blowing. The preceding 2 days had also been relatively calm. Water samples and Secchi disc measurements were taken out from the shore in the morning (see Figure 8, sample stations 14 to 18). During the day, wind velocities increased to about 15-18 km/hr and by mid-afternoon waves up to 0.3m were present in the northern sector of the Bay. A subsequent series of samples were then taken at the same set of stations.

The results of this experiment clearly demonstrated that sediment resuspension is caused by wave action. In this case, an average increase of 12.5 mg/l of suspended solids was generated in the near shore wave break zone over a period of about 7 hours. With stronger onshore winds, much higher levels would have been produced. However the amount of material resuspended is a function of the supply of resuspendable material available which, in turn, is partly related to antecedent deposition and resuspension events.

Direct quantification of the importance of this mechanism to water clarity in the Bay cannot be easily ascertained; but, it can be stated that by significantly reducing the supply of suspendable material this source of turbidity can be reduced.

5.5.2 Physical Damage to SAV

Physical damage to SAV by wave action is more difficult than sediment resuspension to measure directly. Field observations can be used to infer certain relationships. First, along all of the western shoreline north of the Shrewsbury Dock and all along the north and east shorelines directly exposed to wave action, no SAV was found growing in water shallower than 1.6m. In areas, such as drain mouths protected by deltaic sediments, along the banks of the drains themselves, or in protected bays such as those along the east shore, SAV was regularly found growing. In the case of the drainage ditches, water turbidity was the highest recorded, and, therefore, differences in water quality do not explain this distribution pattern.

The historical distribution of SAV determined from aerial photographs during the periods of the milfoil invasion indicated that the plants extended almost to the shoreline and emergent species (eg Nuphar advena) grew along the shore itself. When the dense milfoil beds were present, they were effective wave barriers and protected against wave wash along the shoreline. Once these beds were removed, the emergent vegetation disappeared as did SAV in the immediate littoral zone.

These observations and the results reported in the literature have lead to the conclusion that wave action is a significant factor controlling SAV distribution particularly in the littoral zone out to about 1.6m and in the northern sector of the Bay.

6 AQUATIC ECOLOGY

This section of the report examines the interactions of the various physical, chemical and biological components of the Bay discussed in earlier sections and analyzes the observed or predicted response of the aquatic ecosystem. The major focus is toward SAV, in particular with respect to reveqetation.

6.1 BIOLOGICAL INTERACTIONS

6.1.1 Water Quality / Vegetation Interactions

SAV communities structurally and energetically are similar to terrestrial plant communities characteristic of shaded environments. Water reflects and dissipates incident light, the light extinction rate being highly dependant on water clarity (ie. turbidity). The shading effect of water has perhaps the most profound influence of any environmental factor on SAV growth and distribution (Sculthorpe, 1967). Other water quality characteristics such as nutrient concentrations, toxic substances, and temperature are also important but if inadequate light is available, the other parameters are of no consequence. Given the close relationship between SAV growth and water clarity, and the high turbidity of Rondeau Bay, considerable attention has been given to this water quality parameter.

A variety of strategies are available to SAV species to deal with their shaded environment. Growth form adaptations are perhaps the most observable. M. spicatum grows rapidly to the surface and then spreads across the surface to form a continuous canopy. It is this characteristic that makes it most troublesome in terms of boating and swimming. By concentrating its photosynthetic tissue near the surface, maximum energy production is achieved. Another strategy employed by broad-leafed Potamogeton species is to grow a large leaf surface area to capture energy. Many of these species have combined this growth form with the previous strategy and developed floating leaves. In this way, they capture as much energy as possible while they are growing to the surface and then maximize energy capture with the floating leaves. A final strategy used by plants such as V. americana, E. canadensis, and some Najas species is to develop a highly efficient photosynthetic process and thereby be able to survive on low incident energy levels. These plants tend to concentrate much of their biomass close to the bottom.

The ability of SAV species and communities to tolerate poor water quality is highly contingent on their characteristic growth forms.

For example, species such as Vallisneria are vulnerable to reduced water clarity, since they need some light penetration below the immediate surface; when the transmitted light is significantly reduced they can only compensate with increased photosynthetic efficiency or with growth form adaptations to a limit. Species with their photosynthetic tissues concentrated at the surface are much less stressed by low light levels at depth.

Another effect of high suspended solids concentrations relates to sediment deposition and buildup on leaf surfaces. Broad leaves accumulate relatively greater areal loads of deposited sediments compared to the narrow leaves of species like P. pectinatus and M. spicatum; these deposits can significantly reduce light transmission to leaf chloroplasts (Kemp et al, 1982).

This effect combined with epiphytic growth stimulated by nutrient concentrations can have a major influence on the photosynthetic potential of SAV (Phillips et al, 1978). In fact in the Chesapeake Bay situation, it was concluded that "nutrient enrichment and increased turbidity ... played major roles" in the extensive loss of SAV. Simulation modelling suggested that nutrients were more significant than turbidity (Kemp et al, 1982).

Water quality influences SAV reproduction strategies; vegetative reproduction is by far the dominant process (Sculthorpe, 1967). Seeds may be regularly or intermittently produced but germination rates appear to be quite low. The reason relates back to light availability. A large energy reserve is required by a seed to successfully grow an adequate photosynthesizing surface for self sufficiency. The lowest incident energy is at the bottom and most seedlings are "shaded out" before the higher light energy region near the surface can be reached. As a result, reproduction from seeds in turbid waters is insignificant to SAV reproduction and dispersal.

A number of forms of vegetative reproduction are characteristic of SAV. M. spicatum has spread rapidly throughout North America because of its ability to grow from small segments of stalks. In fact during the fall, as the plants begin to die back, many small apical shoots are released which float at first and then sink. These apical shoots become fixed by roots to the substrate and begin growth as adult plants in the spring. For this to occur, however, adequate light must reach the bottom to support growth since the energy reserve of the shoots is quite limited.

The primary vegetative reproduction mode of V. americana and H. dubia is through rhizomes. Stalks are sent out just below

or at the sediment/water interface. At the terminus a new plant begins to grow which is provided with energy from other plants connected to the rhizome. In this way, the new plant obtains an adequate energy supply to become established under the shaded conditions. Frequently they, like Myriophyllum, may also vegetatively disperse through uprooting of entire plants or stalks.

Some species such as P. pectinatus vegetatively reproduce using rhizomes but in addition form both axillary and subterranean tubers for overwintering. The subterranean tubers provide the new shoots in spring with a large energy reserve. This reproductive strategy permits the species to cope with low light levels but due to the infrequent sporadic dispersal of tubers is not well suited to extensive rapid colonization of new sites. The axillary tubers are more broadly dispersed but they have a much lower energy reserve and are thus less successful in colonizing unfavourable habitats.

The reproductive potential of this species is impressive as demonstrated by Yeo (1965). In one experimental plot under optimal conditions a single specimen of P. pectinatus produced in one growing season 36,000 subterranean tubers, 800 axillary tubers and 6,000 seeds.

6.1.2 Vegetation / Fisheries Interactions

A major limiting factor to fish distribution and productivity relates to habitat quantity and diversity. This relationship in fundamental to much of the recent research on, and testing of the construction of artificial reefs for fish.

In shallow freshwater systems, SAV is an important habitat component for many fish species. The SAV provides a growth surface for invertebrates which are a major fish food source. In addition, it provides cover for small fish to avoid predators. "Weed beds" have long been a favourite fishing spot due to the attraction of many fish species to these areas.

The role of SAV directly in energetic terms to fish productivity is unclear. In most aquatic systems the supply of organic matter exeeds the demand of invertebrates and is not limiting. Often a major supply of organic matter is provided by runoff or wind transport. In the case of Rondeau, this is clearly shown by the high organic content in the sediments entering the Bay (see Section 5.2). Accordingly, most attention on the role of SAV to fish production has been on its structural characteristics as opposed to direct energetic inputs.

In summary, the two major functions of SAV in fish production are to provide:

i) habitats for invertebrates which are a principal food source for many fish species in particular forage and juvenile game fish species

ii) cover and protection for juvenile and adult fish.

6.1.3 Water Quality / Fisheries Interactions

Water quality can directly effect fish through reduced predation efficiency, siltation of spawn, abrasion and clogging of gills, and toxic effects. It is beyond the scope of this report to discuss this topic in detail. The report prepared by the Ontario Ministry of the Environment (1982) addresses this subject and it has been treated extensively in the literature. However, based on current water quality conditions and a preliminary examination of the biological characteristics (age class distribution and growth rate) reported in the creel censuses since 1977 (Hyatt, 1982; Witzel, 1981; Wood, 1978; Dunlop, 1979), direct impacts on the fishery from water quality do not appear to be a significant cause of population declines. Indirect effects appear more significant. Reduced light availability from water quality degradation leading to the decline of SAV is a more likely impact mechanism.

6.1.4 Vegetation/Water Levels

Water levels in Rondeau Bay are controlled primarily by the level of Lake Erie. Water levels in Lake Erie follow pronounced and relatively irregular annual and multiyear cycles. In addition short term fluctuations occur due to seiche (see Section 2.3). This regime of fluctuating water levels is more pronounced and unpredictable than those experienced in smaller inland waters or in many marine environments and it has important implications for SAV.

During periods of high water levels, the area of the Bay capable of supporting SAV can be shifted shoreword significantly. Under low water level conditions, much of the immediate littoral zone is exposed to the air. As a result, SAV is required to alter its distribution periodically. This type of environment places a strong selective preassure on the SAV species to be tolerant of varying water levels and also to be able to readily colonize newly available habitats. In effect, fluctuating water levels act as another environmental variable stressing SAV; constant water levels or regular cycles would encourage the development of stable SAV communities.

6.2 FIELD ANALYSES

This section looks specifically at the ecology of the SAV of Rondeau Bay with particular reference to growth and reproduction and is based on field observations.

6.2.1 Standing Biomass

Table 3 (see Section 4.2.1) presents standing biomass (g dry wt/sq.m) by species and in total for the SAV communities sampled. Several points are noteworthy and support the general results discussed in Section 6.1.

First, the highest standing biomass and greatest species diversity was found in the protected bay located in the extreme south east corner of Rondeau. As discussed in Section 3.2.1, this area has the lowest suspended solids concentrations and hence the greatest light transmission. This observation strongly supports the hypothesis that turbidity is a major limiting factor.

The other area where relatively high standing biomass was encountered was the south west corner of Rondeau Bay. This site was dominated by Heteranthera dubia and had a low species diversity. Water clarity is quite low (see Figure 3) but water depths range between 1.0 and 2.0 m permitting the plants to reach the surface for photosynthesis.

Quantitative sampling was not conducted in the drainage ditches but many supported relatively dense SAV growth with quite high diversity. The shallow depths (ie less than 1 m) and protection from waves appear to be the major factors for this pattern despite the extremely high turbidity in the drainage ditches.

As discussed in Section 4.5, the breaking zone for average significant waves in the Bay is around the 1 to 1.4 m depth. SAV has adapted to waves through the development of flexible stalks and firmly attached roots; however, in zones of intense wave energy (ie breaking zones), physical abrasion can damage the vegetation. Waves seem to be limiting the shoreline distribution of SAV in Rondeau. Much of the shoreline zone in the northern sector of the Bay out to 1.2 to 1.6 m is suitable for SAV growth in terms of substrate and light availability yet virtually no growth is occurring. Historically, growth occurred in this area when dense beds of M. spicatum provided protection from waves (see Section 4.1 and Figure 15).

In summary the observed SAV biomass in most sites is extremely low considering the shallow depth and high nutrient availability of Rondeau Bay.

6.2.2 Seed Bank

A survey was conducted to determine the extent of viable seeds in the sediments(Figure 24). At each site, 4 ponar dredge samples were taken, combined in a sample bag, and stored in a cool place until analyzed. The sites were selected on the basis of current and historic distribution of SAV; in effect, a complete range of deep and shallow, and vegetated and unvegetated sites were sampled.

The results are presented in Table 6 and can be summarized as follow.

i) No significant trend was apparent between the sites sampled.

ii) The dominant seeds present were not those of SAV but of emergent and littoral plant species.

iii) None of the SAV seeds examined contained viable embryos.

On the basis of this analysis, it is concluded that the existing sediment seed bank is not adequate to support extensive natural revegetation of SAV. This situation could change somewhat if the vigor of the SAV were to change substantially in association with improved water quality. But given the limited role of seeds in the reproductive strategies of SAV, their importance for future restoration efforts must be viewed as minimal.

6.3 LABORATORY EXPERIMENTS

Observations of SAV made during the field sampling program provided many insights into the ecology of Rondeau Bay. However, a number of relationships key to future restoration efforts could only be definitively tested through controlled laboratory experiments. Specifically, the sensitivity of three native species of SAV, P. pectinatus, V. americana and H. dubia, to variably light conditions and various sediments types was assessed.

6.3.1 Experimental Procedure

The experiments were conducted in a greenhouse facility made available at the Canada Centre for Inland Waters. Four litre sealed plastic containers were filled with one of the five sediment types and in each container, three specimens of one of the three SAV species were planted. Neoprene collars around the stalks of the plants were used to seal the

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE

SCALE 1:50,000

Depth contours: meters

JEHanna Associates Inc.

SEED BANK
SAMPLE STATIONS

FIG. 24

TABLE 6 RESULTS OF SEDIMENT SEED BANK ANALYSIS

Sample Number	Water Depth (m)	Community Type *	Seed Density (Number of seeds per sq. m)				
			Najas flexilis	Potamogeton pectinatus	Potamogeton natans	Potamogeton c.f.	Polygonum c.f. natans
1	1.1	V/H	0.25	--	2	--	--
2	1.1	V/H	--	--	--	2.25	3.0
3	1.0	V/H	--	--	--	--	--
4	1.0	V/H	--	--	--	--	--
5	--	V-C	--	--	--	--	--
6	--	V-C	--	--	--	2.0	2.0
7	--	V-C	--	--	--	--	0.25
8	--	V-C	--	--	--	--	--
9	--	V-N	--	--	--	--	5.25
10	--	V-N	--	--	--	--	1.5
11	--	V-N	--	--	--	--	--
12	--	V-N	--	--	--	--	1.5
13	--	M-N	--	--	--	--	--
14	--	M-N	--	--	--	--	--
15	--	M-N	--	--	--	--	0.5
16	--	M-N	--	--	--	--	1.25
17,18**	1.4	P	--	--	--	0.25	0.75
19,20	1.4	B	--	--	--	--	0.25
21	1.1	V-N	--	--	--	--	--
22,23	1.1	V-N	--	--	--	--	--
24	1.1	M-N	--	--	--	--	1.5
25,26	1.7	H-M	--	--	--	--	2.0
27	1.5	H-M	--	--	--	--	0.75
28	1.9	H-M	--	--	--	--	1.0
29	1.6	H-M	--	--	--	--	1.0
30,31	2.35	B	--	1	--	--	0.75

* Community types refer to those described in Secction 4.2.3. "B" denotes that the sample station was bare of vegetation and not in one of the SAV communities.

** Where the results of two consecutive stations are the same, they are shown together on one line.

sediments from the water in the tubs. Six replicates (ie. two containers) were grown under each environmental regime yielding a total of 45 containers or 270 individual specimens. Groups of eight or ten containers were placed in 1.6 m deep opaque plastic tubs filled with water. Over the top of each tub, layers of fibreglass mesh screen were placed; the screens were used to control light conditions in the tubs.

Incident light and PAR extinction points were recorded using a photometer and were adjusted by adding or removing screening to replicate average light conditions in the Bay at depths of 1.65m, 1.9m and 2.15m.

At the beginning and end of the growth period, the wet weight of each specimen was measured. During the growth period, weekly measurements of stalk length were made.

Two of the species, V. americana and H. dubia, did not grow well under any of the experimental conditions. As a result, no clear differences among treatments were evident. Conversely, P. pectinatus grew under all treatments with variations between some treatments. As a result, much of the following discussion deals primarily with this latter species.

6.3.2 Effects of Sediment Type on Growth

Average net increase in biomass as a function of initial tuber weight varied substantially between sediment types (Table 7). (Summaries of the growth data for all species and treatments are given in Appendix J). The best overall growth occurred on the deepwater organic silt, although considerable variation in growth response among individual specimens and treatments was noted on this type. The next best sediment was the sandy organic soils found in the protected south east corner; P. pectinatus had the most consistent growth between treatments (ie high germination rates and low mortality) on this type.

Growth was less on the compact clay characteristic of the north west shoreline and less again on the coarse wave-washed sands found along the east shoreline. The poorest increases in growth occurred on the inorganic silts found in the protected near-shore areas of the west shore.

The ranking of the sediments in terms of observed growth increases are consistent with those which would be expected based on observed growth patterns in the Bay and the physiochemical composition of the sediments, with the exception of sediment type 3, silt. This sediment type supported most of the P. pectinatus growth in the protected

TABLE 7 GROWTH RESPONSE OF POTAMOGETON PECTINATUS ON VARIOUS RONDEAU BAY SEDIMENT TYPES.

Sediment Type	Average Biomass Increase per Gram Initial Weight	Average Number of Sprouts per Gram Initial Weight
1 - Compact Clay-R	1.14	2.02
1 - " -N	1.28	2.18
1 - " -I	1.00	2.66
Average for Type 1	1.14	2.29
2 - Deepwater Organic Silt-R	2.44	3.85
2 - " -N	1.13	2.27
2 - " -I	0.81	2.23
Average for Type 2	1.46	2.78
3 - Silt - R	1.14	1.76
3 - " - N	0.84	1.56
3 - " - I	0.81	0.72
Average for Type 3	0.80	1.35
4 - Coarse Sand - R	1.05	1.98
4 - " - N	1.01	2.10
4 - " - I	1.05	1.30
Average for Type 4	1.04	1.79
5 - Sandy Organics - R	1.7	2.72
5 - " - N	1.45	2.93
5 - " - I	1.07	2.58
Average for Type 5	1.41	2.74

mouths of drainage ditches and higher increases in biomass were expected. If these results truly reflect the preferences of P. pectinatus for various growth substrates, it is concluded that wave action or some other environmental variable(s) associated with exposed sites is a more important factor than sediment type in determining its distribution in Rondeau Bay. If this were not the case, the species would be more extensively distributed in the near-shore zone based on the results of the growth experiments.

6.3.3 Effects of Light Regime on Growth

Light had a pronounced effect on shoot growth (Figures 25 to 27). Under reduced light conditions, shoot elongation was more rapid. Interestingly, P. pectinatus was able to grow to the surface of the tubs (ie about 1.4 m) under all light conditions suggesting that it could be planted successfully under existing turbidity conditions in the Bay in water depths equal to 2.15 m or more.

There was a general trend to an increase in the wet weight of the plants with lower light transmission conditions. For all sediment types, except type 4, coarse sand, the lowest weights were associated with the highest light conditions and for four of the five types, the highest average weight increase occurred under the poorest light conditions.

An explanation of this phenomenon cannot be conclusively stated; however, the following should be considered.

i) Under the reduced light conditions, the total length of stalks was greater. Since wet weight was measured, the increased surface area of the stalks and the likely higher water: carbon ratio in the cells themselves could account for the difference.

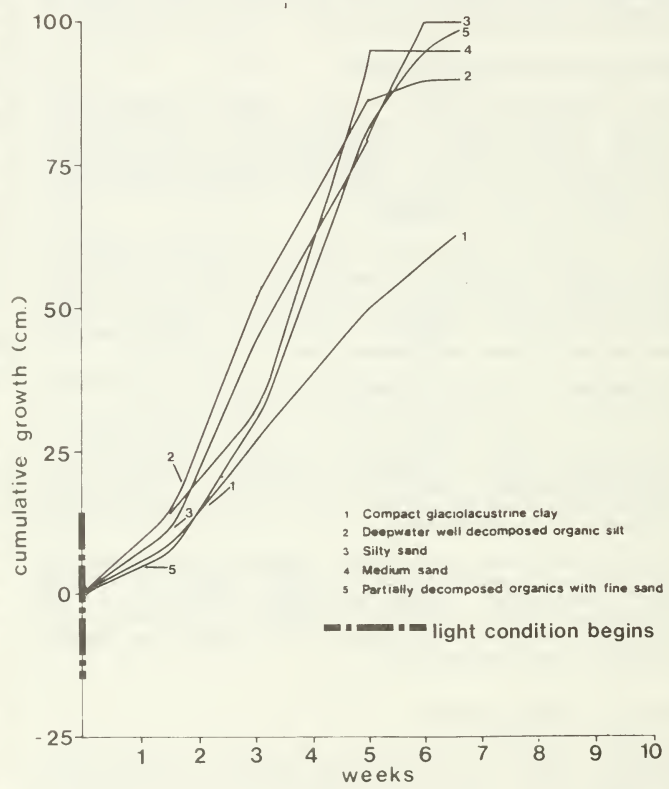
ii) Through the more rapid stalk elongation response, the net energy captured by the plants under the reduced light conditions could have been greater if the increased length of time in the higher light energy zone near the surface was adequate to offset the overall reduced light transmission.

6.3.4 Effect of Initial Biomass

The average increase in biomass and stalks sprouted are expressed as change relative to the initial weight of the tubers (Table 7). This permits comparisons between the values without introducing the effect of initial available energy reserves.

RESTORATION OF AQUATIC VEGETATION

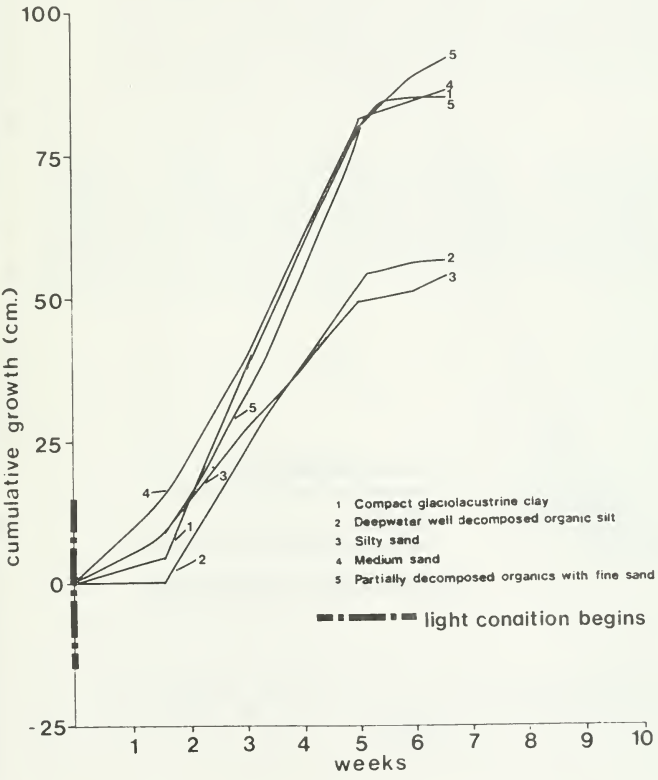
RONDEAU BAY, LAKE ERIE



JEHanna. Associates Inc.	CUMULATIVE GROWTH POTAMOGETON REDUCED LIGHT	FIG. 25

RESTORATION OF AQUATIC VEGETATION

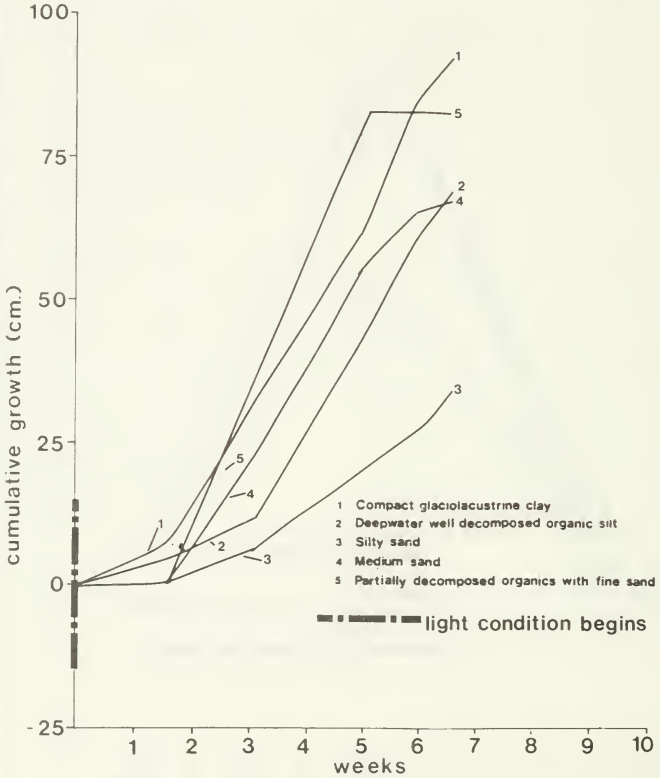
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH POTAMOGETON NORMAL LIGHT	FIG. 26

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH POTAMOGETON INCREASED LIGHT	FIG. 27

If this correction is not made, several relationships can be seen.

i) The increase in biomass is related to initial biomass. In other words, the larger the tuber planted, the greater the biomass which will be produced, at least over the early part of the growth cycle. The exact mechanism is not clear but likely reflects the ability of plants grown from large tubers to reach the surface zone more rapidly and to start net production of biomass sooner, in addition to the greater amount of photosynthetic tissue which can be produced to capture light energy.

ii) Large tubers produce more stalk sprouts.

Both these observations are consistent with the expected results, that is the initial energy reserve available strongly influences growth performance. As a result given the marginal habitat conditions in Rondeau Bay, any tubers used for restoration should be on average, relatively large. Additionaily, sorting of tubers on the basis of weight is advisable prior to planting, and the larger tubers should be planted in the deeper water.

7 ALTERNATIVE MANAGEMENT TECHNIQUES

This section presents i) a summary of the environmental factors affecting viable management techniques, ii) a series of evaluation criteria which were applied to each alternative, and iii) a description and evaluation of specific techniques.

7.1 KEY ENVIRONMENTAL VARIABLES

The following variables must be considered in choosing the type and location of management techniques. These primary variables have been chosen on the basis of the preceding analysis of ecological factors.

7.1.1 Water Clarity

Light limitation appears to be a major constraint to the establishment and growth of SAV. High turbidity is restricting the majority of the existing SAV to grow in water depths not exceeding 1.8 - 2.0 m. Improvements in water clarity would increase the vigour of existing SAV encouraging more rapid outgrowth from existing stands and allowing successful colonization of previously inhabited sites.

Improvements in water clarity can be most significantly achieved through a reduction in suspended solids and secondarily through reduced phosphorus concentrations and associated phytoplankton growth.

7.1.2 Wave Action

Strong wave action appears to physically disrupt and/or damage SAV. Existing stands are most abundant in protected areas. Waves also cause resuspension of sediments leading to reduced water clarity. During the time of milfoil abundance, most of the littoral zone of the Bay was essentially protected from wave action due to the dampening effect of the dense beds.

7.1.3 Plant Material

The majority of Rondeau Bay is devoid of rooted SAV. The absence of rooted plant material secured in the sediments limits the ability of SAV to colonize and expand in new locations. While uprooted plant and broken off stalks are quite abundant in the Bay, they do not appear to be able to become rerooted extensively in new areas.

7.1.4 Other Environmental Variables

Other factors such as presence of chemical pollutants, sediment quality, etc. are secondary. In earlier sections it has been concluded that while they may influence SAV abundance and distribution, their effects are not considered major relative to those factors mentioned.

7.1.5 Habitat Diversity

This environmental variable does not relate specifically to SAV restoration but more precisely to restoration of the fishery. The loss of SAV from the Bay has resulted in a loss in the area and diversity of fish habitat, by increasing habitat diversity through whatever means, an improvement in the fishery is expected to be realized; although, the benefits to SAV per se may be minimal or nonexistent.

7.2 EVALUATION CRITERIA

A number of alternative management techniques are considered for the restoration of SAV in Rondeau Bay. To compare these alternatives effectively both individually and as part of an overall management strategy, a series of evaluation criteria were used.

7.2.1 Cost

Two measurers of cost need be considered. The first is unit cost, that is what will the cost per unit area be to restore SAV at a given site. The lower the areal unit costs the better a given alternative would be rated.

The other measure of cost is the total budget required to effect a technique. With some techniques, there is a minimum level of effort that can be expended to acheive an effective result. The lower the minimum initial cost the better an alternative would be ranked. (Consideration of minimun level of effort is particularly important in the assessment of management strategies).

7.2.2 Level of Technical Sophistication

Some techniques require considerable expertise in terms of selecting materials for restoration, their placement and their maintenance. This criteria has implications in terms of costs; if skilled labour is required and is not available locally, costs can increase substantially. Techniques which could be implemented with relatively unskilled labour and minimum supervision and direction are preferred over more sophisticated approaches.

7.2.3 Reliability

Proven techniques that have demonstrated repeated success are considered better than less well-tested approaches. This criteria is a relative measure since none of the restoration techniques for freshwater SAV have been tried or studied extensively.

7.2.4 Flexibility

Techniques which can be readily adapted or moved from one site to another are preferred to less mobile or adaptable alternatives. Associated with this criteria is the range of conditions under which the strategy will likely be effective and the sensitivity of the approach to variations in ambient conditions.

7.2.5 Permanence

This criteria reflects the operating and maintenance requirements associated with a strategy. Those requiring the least effort in terms of operation and maintenance are preferred. The life expectancy of the overall approach is contained in this criteria. In other words, self-perpetuating strategies are preferred to shorter-term solutions.

7.2.6 Benefits

Benefits of a strategy must be reviewed in relation to four potential types of return, namely:

i) increased fish production (ie improved habitat)
ii) improved waterfowl habitat
iii) recreation opportunities
iv) aesthetic values (visual impacts, change in water clarity, etc).

Benefits under recreational opportunities include active recreational pursuits exclusive of fishing and waterfowl hunting and viewing (ie sailing, motor boating, water skiing, etc.). Benefits under aesthetic values relate to intangible returns that could be experienced by any user group of the Bay.

Secondary benefits such as "ripple effects" from increased tourist activity, spinoffs in local revenues, employment, etc. are not considered, but these will clearly result from increases in the benefits described above.

7.3 MANAGEMENT TECHNIQUES

Management techniques have been divided in to two basic types, namely "hard and soft". Hard techniques involve the physical construction or installation of devices or structures and prescribed chemical treatments. "Soft" technique relate to biological or management resources that do not require specific structures.

Hard techniques considered include wave barriers, artifical reefs, sea curtains and alum. Soft techniques include natural regeneration, SAV planting and reduction in sediment to the Bay through soil conservation practices. Each are briefly outlined below.

7.3.1 Wave Barriers

A number of types of wave barriers have been suggested ranging from mats of cattails to floating tire barriers. The technology associated with floating tire barriers is fairly well developed (Bishop 1980) and has been successfully used under a range of environmental conditions (Allen and Webb, 1983; Bishop and Gallant, 1981). The barriers effectively absorb wave energy and have been used for harbour and shoreline erosion protection. A major advantage of the technology is the low capital cost compared to conventional breakwalls (ie in the order of $ 90 to $ 200 per linear meter).

Once in place the structures are quite permanent and are not easily relocated. They can be used in a variety of situations and are quite reliable. Construction of the barriers is straightforward although anchoring requires more skill and sophistication.

By reducing wave action, barriers can:

i) prevent physical damage and disruption to SAV;
ii) reduce resuspension of sediments, and
iii) provide limited habitat diversity for fish.

The barriers do obstruct boat traffic although navigation channels can be left. In addition, they could be deemed to have a negative visual impact.

7.3.2 Artificial Reefs

The use of artificial reefs to enhance fisheries production has received increasing attention from fisheries biologists since about the mid 1970's. Many of the applications of this technique have been in marine environments using abandonned oil rigs, ships and other types of structures. The reefs provide a substrate for epiphytes and invertebrates that are food for forage and juvenile game fish species. These in

turn depend on the structure for protection. Large predatory fish are attracted to the concentrations of forage fish and also use the structure for cover.

Artificial reefs need not consist of metal structures, and sunken trees can also be used. Another variety consists of polypropylene ropes anchored to the bottom. These strands extend up into the euphotic zone in much the same way as real SAV and provide a substrate for epiphytes and invertebrates (Knopf, 1984). The effectiveness of an artificial reef is dependent on the surface area available for epiphyte and invertebrate attachment, the diversity of the water compartments provided, and the depth of the structure relative to light penetration (generally, the greater the incident radiation to the surface of the reef, the higher the relative productivity).

The cost of artificial reefs is usually primarily a function of labour requirements since the actual materials used are normally regarded as waste. Installation is straightforward, the major consideration being the specific location for each structure. Artificial reefs have proven to be reliable in marine environments but have not been studied as extensively in freshwaters, particularly highly turbid waters such as those characteristic of Rondeau Bay. Once a reef is installed, it is essentially an immobile structure and its life expectancy is dependent on its initial condition and composition and the environmental conditions of the site (eg, wave-washed vs protected, etc).

Artificial reefs are expected to have primary benefits to the fishery with little effect on the distribution or abundance of SAV. Depending on location and depth, they could pose a hazard to boating traffic and would require appropriate marking.

7.3.3 Sea Curtains

Sea curtains are made of durable plastic film; they have floats at the surface and anchors on the bottom. These curtains were originally designed primarily to close off columns of water for limnological research, and are effective in preventing water exchange.

The use of sea curtains to contain large or small areas of the Bay to improve water clarity and to stimulate SAV growth has been suggested.

A 225 metre curtain costs about $ 55,000 plus anchoring material and smaller versions around 50 metres would cost about $6,000 (S.Takeguchi, pers. comm.). Relatively unskilled labour is required for installation. The curtains are susceptible to vandalisms and weather damage and require a certain amount of maintenance. They are relatively easily

moved from one site to another and would work well under the conditions present in the Bay. Once the curtain is removed, the effect is lost. However, this technique could be used to establish in the first growing season a strong self-pertpetuating stand.

The primary benefit of the technique would be the restoration of SAV and associated benefits therefrom. The curtains can be a hazard to navigation, although they can easily be marked. Any visual impacts would be transitory.

7.3.4 Alum Treatment

Alum (aluminum sulphate) is regularly used in water treatment plants as a clarifier. The alum forms a floc which absorbs suspended particles and percipitates these out of suspension. It also combines with dissolved phosphorus to reduce concentrations of this nutrient.

Alum is available as a wet slurry and is mixed with lake water often by prop wash. Dosage rates would be in the order of 3 tonnes/ha and the chemical costs about $ 240/tonne delivered (B.McLean, Allied Chemical, pers. comm.). For this treatment to be effective, the majority or all of the surface area of the Bay would need to be treated. A major constraint with this approach is the unpredictability of the weather. If a major wavestorm or runoff event was to occur in the middle or immediately following the treatment, water turbidity could return to current levels almost immediately. Accordingly, this technique is considered feasible only on a limited basis for specific applications where the effects are expected to be longer lasting.

7.3.5 Natural Revegetation

Natural revegetation of SAV depends on the existing plant stocks supplying sufficient vegetative parts and seeds for recolonization. Records delimiting the boundaries of existing SAV since 1977 are absent; as a result, it was not possible from this study to determine if the existing stands have expanded or at what rate. If an expansion has occurred, it is quite slow and it is estimated at least 10 to 15 years would be required for any substantial increase in SAV to occur given estimated current rates of recolonization and water quality conditions.

The major mechanism for expansion is expected to be through extensions of existing beds by rhizome shoots. Seed germination is typically of minor importance in the reproductive strategy of SAV (Sculthorpe, 1967), and is likely to be of even less importance in Rondeau given the adverse light and wave conditions. Scattered new colonies may result from uprooted plants rerooting in new locations but this does not appear to be occurring very rapidly at

present, particularly in light of the abundant stock of uprooted plants observed during the field program.

There are no costs associated with this technique although the reliability is highly uncertain and the recovery time could be extensive.

7.3.6 SAV Seeding

Artificial seeding has been attempted for marine SAV species in particular Zostera marina but the results have generally been much poorer than for transplanting of vegetative parts (Churchill et al, 1978). No similar efforts were found to be reported for freshwater SAV. Given the marginal light conditions in Rondeau Bay, the expected success of SAV seeding is low. In addition, no SAV seed suppliers were located, which would necessitate seed to be harvested, transported, and stored for application specially for this project.

This technique is not considered feasible and will not be considered further.

7.3.7 SAV Transplanting

The majority of the marine projects relating to SAV rehabilitation have employed various methods of transplanting vegetative parts. An exhaustive discussion of the benefits and constraints of the various methods is provided by Thorhaug and Austin (1976) and Phillips (1974). These methods require a source of transplant material to be identified and the material to be collected and prepared for planting. Then the material must be planted at the new site. This process is labour-intensive and does require a moderate level of skill and care.

Some of the techniques reported for marine species include

i) planting individual specimens by hand
ii) attaching specimens to nets or ropes which are then anchored to the bottom
iii) removing plugs of vegetation in cores and then inserting the plugs in holes at the new site
iv) using bricks to provide stable substrates and planting individual specimens in the holes.

A technique not reported in the literature but used by hunting clubs for planting preferred species of SAV in waterfowl ponds, in particular P. pectinatus, involves weighting individual tubers and scattering them by hand from the surface. This technique has proven quite successful on a number of occassions and environmental settings.

The techniques tested in marine environments require a moderate level of skilled labour and per unit area costs have been reported ranging between $3,200 and $160,000/ha planted (Fonseca et al, 1982; Churchill et al, 1978; Thorhaug and Austin, 1976.).

Planting stock of P. pectinatus tubers costs in the order of $125.00/1,000 tubers and would require an application rate of 5,000 to 10,000 tubers/ha. Relatively unskilled labour is required for application.

The marine transplanting techniques work best in relatively protected waters with fairly easily penetrated sediments and would be feasible for some sites in Rondeau. Similarly, the tuber method works best where wave action is minimal and a good rooting substrate is available.

Once the plants are in place they cannot be moved; however, if the proper sites are selected and water quality conditions do not deteriorate, the transplants will be self-perpetuating. Areas treated with transplants can be expected to reach a natural equilibrium in terms of abundance within 2 to 3 growing seasons providing no external disruptions occur.

Natural SAV communities will provide habitat for fish, forage for waterfowl especially P. pectinatus, and may reduce suspended solids to a certain degree. Provided that growths do not reach the densities of milfoil in the early 1970's, no major constraint to other recreational pursuits are expected.

7.3.8 Soil Erosion Prevention

This technique is somewhat different than all others mentioned in that it is directed at the Rondeau watershed as opposed to the waterbody itself. A first step in this technique has been the Master Erosion Control Plan. The basic concept is to improve soil conservation practices in the watershed and thereby reduce sediment export. In turn, the supply of suspended solids to the Bay may be reduced.

Techniques of soil conservation such as conservation tillage, contour ploughing, grassed buffer strips and ditches, etc. have proven to be successful in reducing soil losses from agricultural land. They have been less vigorously studied, however, in terms of associated improvements in water quality in particular water clarity.

For example in the Chesapeake Bay watershed, soil losses have been reduced by over 3 times the levels in the late 1960's and early 1970's but turbidity from suspended mineral solids in the estuary has remained high (Kemp et al, 1982). The reason is that only a fraction of the total soil lost from agricultural land stays in suspension for extended periods of

time (see Section 3.2.1) but that fraction which is readily suspendable is often the most difficult to stop from eroding. Accordingly in terms of total mass of eroded material, the suspended solids component may not be significant from the perspective of total soil loss and reduced agricultural production, but it has a dramatic effect from the point of view of water clarity.

In summary, soil conservation techniques are effective in reducing total soil losses; however, in terms of significantly reducing suspended solids concentrations and increasing water clarity, their net effect is less certain.

From a cost perspective, the Master Erosion Control Plan concluded that some improvements in soil conservation would yield net positive returns to private landowners without considering public benefits. As a result, these practices will likely be implemented regardless of the potential positive benefits to Rondeau Bay.

A question which was beyond the scope of this study is what change in average suspended solids in the Bay these erosion control measures will have. Or conversely, what degree of soil erosion protection is required to reduce average suspended solids concentrations in the Bay by 50% or more?

7.4 SUMMARY

This section has presented the key evaluation criteria that should be used to assess individual management techniques and overall restoration strategies. It also described the individual techniques which have been considered for application in Rondeau Bay.

A large number of combinations of techniques in terms of level of effort and their spatial and temporal distribution is possible and many cannot be rejected outright. Given this fact, a great number of alternative strategies could be feasibly devised. To provide a starting point, a recommended restoration strategy is presented in Section 8.0 but full consideration should be given to the high degree of uncertainty associated with the management techniques presented. Any restoration strategy must recognize that the rehabilation of freshwater SAV in comparable situations to Rondeau Bay has virtually not been attempted. The largest comparable effort has been directed at the Chesapeake Bay situation yet despite expenditures several orders of magnitude greater than those available here, conclusive research results are not available nor has extensive rehabilation of SAV been achieved.

Greater experience has been gained in restoring SAV in marine environments but these applications have dealt primarily with disturbed sediments devoid of vegetation and not sites unvegetated due to water quality effects such as is the case in Rondeau Bay.

8 RECOMMENDED RESTORATION STRATEGY

The following strategy draws from the techniques presented and combines them in terms of level of effort and spatial and temporal distribution.

A definite budget ceiling has not been decided by the Ontario Ministry of the Environment and related agencies in terms of the level of expenditure available to restore the Bay, but for the purposes of this analysis a ceiling of $400,000.00 has been assumed. It is also assumed that this money could be spent over a maximum of 4 years.

8.1 DESCRIPTION OF RECOMMENDED STRATEGY

The recommended strategy consists of the following techniques

i) transplanting of P. pectinatus tubers,
ii) soil conservation measures.

The basic concept is to plant patches of P. pectinatus progressively out from the current boundaries of SAV stands.

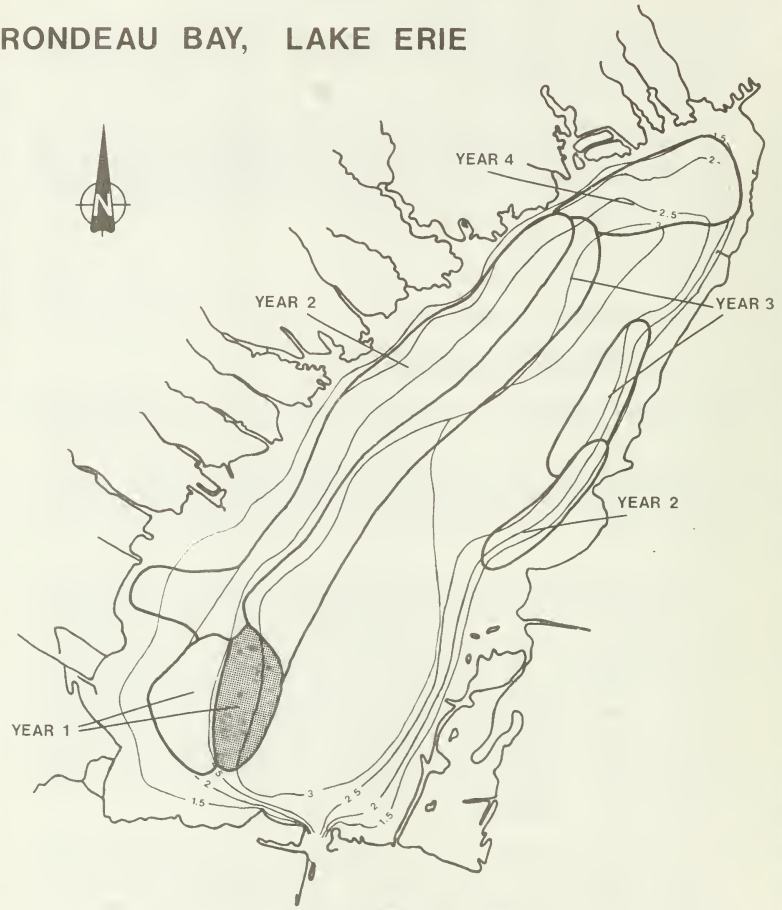
The soil conservation component consists of a level of effort consistent with that proposed in the Master Erosion Control Plan. Given such measures, it is expected water clarity in the Bay will not deteriorate and some improvements might occur.

It is suggested that two additional techniques, namely, sea curtains and alum treatment, be used on an experimental basis in deeper water if the first year's growth in this zone is not adequate. The idea is that areas would be encircled by sea curtains and the water column treated with alum for rapid clarification. Subsequently, they would be planted with tubers. This technique would be used in water depths from 2-3 m where light conditions are marginal. It will provide one growing season for the plants to become well established before they are subject to reduced light conditions. Due to the capital and labour expenses associated with this technique, it can only be applied on a limited scale in areas of particular importance for fish habitat.

In the first year, total expenditures of approximately $50,625 would be required. (Section 8.5 provides for more detail regarding cost estimates). The suggested locations of the plantings for the four years are shown on Figure 28. A portion of the area to be planted in the first year is shaded; in this deeper zone germination of the tubers may not be as successful as in the shallower water. If so, the sea curtain technique should be attempted first in this area.

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.

DISTRIBUTION AND PHASING OF RESTORATION EFFORTS

FIG. 28

The limited level of effort in the first year will provide an opportunity for some experience to be gained with the tuber transplanting technique without a major budget commitment.

8.2 RATIONALE FOR RECOMMENDED STRATEGY

The above strategy has been recommended for the following reasons.

1) The transplanting of P. pectinatus tubers is one of the least expensive techniques on a per unit area treated. Tubers are readily available from suppliers and they can be planted by relatively unskilled labour.

2) P. pectinatus was the only native species of SAV regularly observed growing in waters in excess of 2.5m and during the laboratory experiments, it performed best in terms of growth under all light conditions. The tubers of the plants are favoured waterfowl forage and the plants provide good habitat for fish species.

   There is a potential that waterfowl grazing could impede the colonization process. For example in Britain (Jupp and Spence, 1977) and elsewhere (Kiorboe, 1980), waterfowl feeding on SAV has been shown to limit the distribution and abundance of stands. The magnitude of this impact will need to be assessed as part of the monitoring component of the project.

3) The progressive expansion of current SAV communities has advantages in terms of plant establishment and fish habitat. Areas where SAV is currently growing are obviously capable of supporting growth and therefore are most likely to successfully support transplanted stock. In addition by developing continuous beds of SAV, they are less susceptible to scouring and wave damage and internal water clarity conditions may be improved (Kemp et al, 1982).

   More fish are more likely to inhabitat contiguous patches of SAV as opposed to isolated islands. By closely spacing the patches, they become accessible to a greater number of fish.

4) The soil conservation measures provide a means to reduce the total sediment load to the Bay and hopefully the suspended solids load also. If a better understanding of the relationship between reduced soil erosion and subsequent reductions in suspended solids loads were available, it is possible that greater emphasis on this component would be given.

5) The limited first year's effort is intended to avoid large expenditures on measures which provide low return. The first year is seen as a pilot effort to test the approaches in situ. Assuming the success of these techniques, the level of effort is expanded in subsequent years.

6) The use of sea curtains and alum is suggested on an experimental basis as a means to encourage tubers planted in deeper water to become well established prior to being exposed to ambient marginal light conditions. The energy reserves built up in the tubers the first year will assist shoots in successive years to reach above the compensation point depth and to capture adequate energy to sustain future growth. This is the most expensive component of the program on an areal basis but may be used for recolonization of critical areas.

7) The other more expensive techniques have not been recommended at this time. If the use of P. pectinatus tubers is successful, this technique is more cost effective than any of the other approaches. Should the transplanting scheme as proposed fail, then other techniques described will need to be considered.

8.3 REQUIRED RESEARCH SUPPORT

Supporting research in the form of monitoring is required to assess the effectiveness of the individual techniques and the strategy overall. In addition, specific research project on other aspect of SAV ecology should be considered.

Monitoring requirements will consist of measuring (using non-destructive techniques) sprouting success in relation to general location, wave exposure, water depth, and sediment type. In addition, comparative studies between beds planted with and without the sea curtain and alum should be conducted. Regular observations of waterfowl distribution relative to planted SAV beds should be undertaken and if heavy grazing is suspected, experiment exclosures should be constructed.

Research or transplanting marine SAV has demonstrated the prevalence of ecotypes within a species which are adapted to specific site conditions. (Phillips, 1974). The selection of appropriate ecotypes has been shown to be particularly important to the successful establishment of new SAV stands. The original environmental conditions from which tubers of SAV are obtained for planting should be carefully documented. If possible, tubers should be obtained on an experimental

basis from several different types of sites and their relative survival documented in the environmental conditions of Rondeau Bay. It is expected that tubers from similar sites will have the highest survival and vigour.

A number of associated research projects on SAV ecology could be considered; however, particular consideration should be given to the dynamics of the milfoil population in reponse to the transplanting effects. Milfoil was observed to be closely associated with existing stands of SAV and its presence in newly-established stands should be closely scrutinized. If another invasion of milfoil were to be initiated, much of the recolonized native SAV might be lost in addition to potential large losses in terms of recreational occasions, particularly boating and waterskiing.

Research requirements concerning the response of fish populations have not been considered only because they are beyond the scope of this report. They should be discussed with the appropriate agencies (ie MNR).

Efforts should be made to project changes in the suspended solids load to the Bay with any soil conservation measures proposed. This information should be used to predict future water clarity conditions in the Bay and to develop an optimal level of erosion control on the basis of both private and public benefits. The results of such analyses will be quite pertinent in terms of the locations and extent of future SAV restoration efforts.

8.4 SCHEDULE

This schedule pertains only to the first year of the restoration program and deals specifically with implementing the restoration strategy and the supporting research components.

The critical time in the program is the date at which the planting of the tubers begins. Ideally, planting should occur in the first week of May when water temperatures are around 10^{o} C. Based on the level of effort recommended, planting will require about 7-10 days.

Tubers need to be ordered from the United States and an export permit is required from Agriculture Canada. Processing of the permit takes about 1-2 weeks and the permit must be processed prior to shipping. Processing of the necessary phytosanitary certificates in the United States takes about 1 week. In light of these time constraints, the restoration program must be initiated by late March at the latest.

Monitoring studies can be conducted throughout the growing season but the critical time for assessment of transplant success will be mid August. In addition provision should be made for subsequent monitoring of select plots for at least 2 additional growing seasons.

8.5 BUDGET ESTIMATE

The following cost estimates are intended to provide a general understanding of the budget required to implement the strategy recommended. The costs may vary somewhat according to labour wages and capital and equipment costs; however, such adjustments can be readily made to the itemized totals. More detailed estimates should be based on firm quoted prices from suppliers and precise labour rates.

Table 8 provides a breakdown of implementation costs for the first year and Table 9 outlines the projected costs over the four years of the program.

These cost estimates do not include costs for monitoring or supporting research and relate only to the actual implementation of the restoration strategy.

If the sea curtain approach proves necessary due to poor growth response in the deeper waters, the budget estimate would need to be modified accordingly. Due to the high capital cost associated with these structures and the relatively small area treated, the total budget is very sensitive to the number employed. As a result, an estimate of these costs has not been made.

TABLE 8 COST ANALYSIS FOR FIRST YEAR OF RESTORATION PROGRAM

Materials		
Area to be Planted	150 ha	
Average number of tubers per sq m	0.25	
Total number of tubers required $0.5*10^4*150=$	375,000	
Unit cost of tubers $125.00/1,000		
Total cost of tubers $375*125		$46,875.00
		$46,875.00
Labour		
Ordering and organizing program	7 days @ $200.00/day	$1,400.00
Planting crews		
- student labour	10 man days @ 40.00/day	$400.00
Supervisor	5 man days @ 100.00/day	$1,000.00
		$2,800.00
Expenses		
- Accomodation	$40.00/day	$600.00
- Equipment		$200.00
- Travel		$150.00
		$950,00
TOTAL COST		**$50,625,00**

TABLE 9 COST SUMMARIES FOR FOUR YEARS OF RESTORATION PROGRAM

Materials			
Area to be planted	Year 1	150 ha	
	Year 2	510 ha	
	Year 3	380 ha	
	Year 4	160 ha	
Total cost of tubers	Year 1	$ 46,875.00	
	Year 2	$158,400.00	
	Year 3	$108,700.00	
	Year 4	$ 50,000.00	$ 363,975.00
Labour			
	Year 1	$ 2,800.00	
	Year 2	$ 11,000.00	
	Year 3	$ 6,000.00	
	Year 4	$ 3,000.00	$ 22,800.00
Expenses			
	Year 1	$ 950.00	
	Year 2	$ 3,600.00	
	Year 3	$ 2,400.00	
	Year 4	$ 1,000.00	$ 7,950.00
		TOTAL FOR PROGRAM	**$ 394,725.00**

9

BIBLIOGRAPHY

The following documents include both specific articles referenced in the preceding text and others which were reviewed over the course of the study. Many of the entries relate to the ecology and/or restoration of aquatic vegetation. Additionally, articles dealing specifically with the aquatic environment of Rondeau Bay have been included.

Adams, M.S. and R.T. Prentki. 1982. Biology, metabolism and functions of littoral submersed weedbeds of Lake Wingra, Wisconsin, USA: A summary and review. Arch. Hydrobiol. Suppl.62,3/4:333-409.

Adams, M.S. and M.D. McCracken. 1974. Seasonal production of the Myriophyllum component of the littoral of Lake Wingra, Wisconsin. J.Ecol. 62:457-467.

Adams, M.S., J. Titus, and M. McCracken. 1974. Depth distribution of photosynthetic activity in a Myriophyllum Spicatum community in Lake Wingra. Limnol. Oceanogr. Vol. 19, No.3, pp.377-389.

Agami, M., S. Beer, and Y. Waisel. 1980. Growth and photosynthesis of Najas marina L. as affected by light intensity. Aquatic Botany 9:285-289.

Aiken, S.G. 1981. An experiment relating vegetative morphology of Myriophyllum alterniflorum (D.C. (Haloragaceae) to growth substrate. Aquatic Botany 10:383-388.

Aiken, S.G. and K.F. Waltz. 1979. Turions Of Myriophyllum exalbescens. Aquatic Botany 6:357-363.

Allen, H.H. and J.W. Webb. 1983. Erosion control with salt marsh vegetation. Coastal Zone 1983. pp.735-748.

Anderson, M.G. 1978. Distribution and production of sago pondweed (Potamogeton pectinatus L.) in a northern prairie marsh. Ecology, 59(1), pp.154-160.

Anonymous, no date. How to Build a Floating Tire Breakwater. Information Bulletin #1. University of Maine/University of New Hampshire Cooperative Institutional Sea Grant Program. 12p.

Anonymous, no date. Rondeau Park Draft Master Plan. Prepared for Ontario Ministry of Natural Resources.

Atmospheric Environment Service. 1983. Meteorological Records, Windsor, Ontario. Environment Canada, Downsview, Ontario.

Barko, J.W. 1980. The influence of selected environmental factors on submersed macrophytes - a summary. Symposium of Surface Water Impoundments ASCE/June 2-5, 1980: 1378-1382.

Barko, J.W. and R.M. Smart. 1980. Mobilization of sediment phosphorous by submersed freshwater macrophytes. Freshwater Biology 10:229-238.

Barko, J.W. and R.M. Smart. 1981a. Sediment-based nutrition of submersed macrophytes. Aquatic Botany 10:339-352.

Barko, J.W. and R.M. Smart. 1981b. Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. Ecological Monographs 51(2):219-235.

Barko, J.W. 1982. Influence of potassium source (sediment vs. open water) and sediment composition on the growth and nutrition of a submersed freshwater macrophyte (Hydrilla verticillata (L.f.) Royle. Aquatic Botany 12:157-172.

Barko, J.W., D.G. Hardin, and M.S. Matthews. 1982b. Growth and morphology of submersed freshwater macrophytes in relation to light and temperature. Canadian Journal of Botany 60 (6):877-887.

Barko, J.W. and G.J. Filbin. 1983. Influences of light and temperature on chlorophyll composition in submersed freshwater macrophytes. Aquatic Botany 15:249-255.

Barko, J.W. and R.M. Smart. 1983a. The growth of Myriophyllum spicatum L. in relation to selected characteristics of sediment and solution. Aquatic Botany 15:91-103.

Barko, J.W. and R.M. Smart. 1983b. Effects of organic matter additions to sediment on the growth of aquatic plants. Journal of Ecology 71:161-175.

Bayley, S. 1978. Changes in submerged aquatic macrophyte populations at the head of Chesapeake Bay, 1958 - 1975. Estuarine 1 (3):73-84.

Beer, S. and R.G. Wetzel. 1982. Photosynthesis in submersed macrophytes of a temperate lake. Plant Physiol. 70,488-492.

Berst, A.H. 1950. Rondeau Bay Fishery Survey. Unpublished Report. Ontario Ministry of Natural Resources. 25p.

Best, E.P.H. 1982. Effects of water pollution on freshwater submerged macrophytes. Water pollution and management reviews 1982. pp.27-56.

Best, E.P.H. 1982. The aquatic macrophytes of Lake Vechten. Species composition, spatial distribution and production. Hydrobiologia 95,65-77.

Best, E.P.H. 1982. Hormonal interactions in Ceratophyllum Demersum. Aquatic Botany, 13:87-95.

Best, E.P.H. 1982. Growth modelling in aquatic macrophytes. Studies on aquatic vascular plants, pp.102-111.

Best, E.P.H. 1981. A preliminary model for growth of Ceratophyllum demersum L. Verh.Internat.Verein.Limnol. 21:1484-1491.

Best, E.P.H. 1981. The submerged aquatic macrophytes in Lake Maarsseveen I: species composition, spatial distribution and productivity. Hydrobiological Bulletin vol.15:72-81.

Best, E.P.H. 1979. Effects of nitrogen on the growth and nitrogenous compounds of ceratophyllum demersum. Aquatic Botany, 197-206

Best, E.P.H. 1978. Growth substances and dormancy in Ceratophyllum demersum. Physiol.Plant.45:399-406.

Best. E.P.H. 1977. Seasonal changes in mineral and organic components of Ceratophyllum demersum and Elodea Canadensis. Aquat.Bot., 3:337-348.

Best, E.P.H., M.C.I. Blaauboer, Th.E. Cappenberg, H.J. Gons, R.D. Gulati, W.A.De Kloet, C.L.M. Steenbergen, and H. Verdouw. 1978. Towards an integrated study of the ecosystem of Lake Vechten. Hydrobiological Bulletin, vol.12,2, pp107-118.

Best, E.P.H. and J.T. Meulemans. 1979. Photosynthesis in relation to growth and dormancy in Ceratophyllum demersum. Aquatic Botany 6:53-65.

Best, E.P.H. and J.T. Meulemans. 1978. Primary productivity in the submerged aquatic macrophyte Ceratophyllum demersum. Verh. Internat. Verein Limnol. 20:88-93.

Best, E.P.H. and R. Soekarjo. 1976. Seasonal effects in the hormonal control of growth in the submerged aquatic macrophyte Ceratophyllum demersum. Physiol.Plant.38:249-256.

Best, E.P.H. and H.W.C. Visser. 1983. The Role of storage substances in growth of Ceratophyllum Demersum L. Pro. Internat. Symp. on Aquatic Macrophytes, pp.25-29.

Best, E.P.H. and J.P.v.d. Wittenboer. 1978. Effects of paraquat on growth and photosynthesis of Ceratophyllum demersum and Elodea Canadensis. Pro. EWRS 5th Symp. on aquatic Weeds. pp.157-162.

Best, P.H. 1981. Productivity and seasonal resource allocation of submersed macrophytes. XIII Internat.Bot.Congress, Sydney, Australia. 6p.

Bishop, C.T. 1982. Research into Floating Tire Breakwaters and the Headland defence of Coasts. Study No. 353/352, Canada Centre for Inland Waters, Environment Canada. 5 pp.

Bishop, C.T. 1982. Floating Tire Breakwater Buoyancy Requirements. Study No. 353, Canada Centre for Inland Waters, Environment Canada. 5 pp.

Bishop, C.T. 1980. Design and Construction Manual for Floating Tire Breakwaters. Unpublished report. National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario. 114p.

Bishop, C.T. 1980. Introduction to floating tire breakwaters. In Proceedings Canadian Coastal Conference. Burlington, Ontario, p.230 (abstract).

Bishop, C.T. and B.A. Gallant. 1981. Construction Of Goodyear Floating Tire Breakwater At La Salle Marina, Burlington, Ontario. Canada Centre for Inland Waters, Environment Canada. 18p.

Boon, J.J., W. Windig, W Wetzel, and G.L. Godshalk. 1983. The analytical prolysis of particulate residues of decomposing Myriophyllum heterophyllum. Aquatic Botany 15:307-320.

Bristow, J.M., A.A. Crowder, M.R. King, and S. Vanderkloet. 1977. The growth of aquatic macrophytes in the Bay of Quinte prior to phosphate removal by tertiary sewage treatment (1975-1976). Naturaliste Can. 104:465-473.

Bristow, J.M. and M. Whitcombe. 1971. The role of roots in the nutrition of aquatic vascular plants. Amer.J.Bot. 58(1):8-13.

Brown, D.M., G.A. McKay, and L.J. Chapman. 1980. The climate of southern Ontario. Climatological studies number 5. 66 p.

Carpenter, S.R. 1979. The decline of Myriophyllum spicatum in a eutrophic Wisconsin lake. Can. J.Bot. 58:527-535.

Carpenter, S.R. and M.S. Adams. 1979. Effects of nutrients and temperature on decomposition of Myriophyllum spicatum L. in a hard-water eutrophic lake. Limnol. Oceanogr. 24(3), 520-528.

Carpenter, S.R. and M.S. Adams. 1978. Macrophyte control by harvesting and herbicides: Implications for phosphorus cycling in Lake Wingra, Wisconsin. J.Aquat. Plant Manage. 16:20-23.

Churchill, A.C., A.E. Cok, and M.I. Riner. 1978. Stabilization of subtidal sediments by the transplantation of the seagrass Zostera Marina L. New York Sea Grant Report Series. NYSSGP-RS-78-15.

Cooke, G.D. 1980. Lake level drawdown as a macrophyte control techinique. Water Resources Bulletin 15(2):317-322.

Correll, D.L. and T.L. Wu. 1982. Atrazine toxicity to submersed vascular plants in simulated estuarine microcosms. Aquatic Bot. 14: 151-158.

Davis, G.J. and M.M. Brinson. 1980. Responses of Submersed Vascular Plant Communities to Environmental Change. Prepared for: Fish and Wildlife Service, U.S. Department of the Interior. 70p.

Davis. G.J., and M.M. Brinson. 1978. Responses of submersed vascular plant communities to turbidity and light transmission. Fish and Wildlife Service, U.S. Dept. of Interior. 100p.

Dunlop, W.I., and L. Sztramko. 1979. Summer Creel Census on Rondeau Bay Lake Erie 1978. Lake Erie Fisheries Assessment Unit Report 1979-3. Ontario Ministry of Natural Resources. 44p.

Dvorak, J. and E.P.H. Best. 1982. Macro-invertebrate communities associated with the macrophytes of Lake Vechten: structural and functional relationships. Hydrobiologia 95,115-126.

Ecologistics Limited. 1983. Master Erosion Control Plan for the Rondeau Bay Watershed. Prepared for: Ontario Ministries of Environment, Natural Resources, and Agriculture and Food. 115p.

Eleuterius, L.N. 1975. Submergent vegetation for bottom stabilization. Estuarine Research 2: 439-456.

Environment Canada. 1983. Sampling for Water Quality. Water Quality Branch, Inland Waters Directorate. Published by Minister of Supply and Services Canada. ISBN 0-662-12380-8. 55p.

Evans, G.C., R. Bainbridge, and O. Rackham. 1974. Light as an Ecological Factor: II. Blackwell Scientific Publications, Oxford. 593p.

Finlay, B. 1984. Pers. comm. Atmospheric Environment Services, Environment Canada, Downsview, Ontario.

Fonseca, M.S. 1982. A Cost-evaluation technique for restoration of seagrass and other plant communities. Environmental Conservation 9(3):237-241.

Ford, J.S. 1981. Prototype designs for surveys and measurement in an aquatic environment. ES-549(6).

Forney, D.R. and D. Davis. 1981. Effects of low concentrations of herbicides on submersed aquatic plants. Weed Sci. 29: 677-685.

Garbisch, Jr.., E.W. No date. Biotic techniques for shore stabilization. Estuarine Research 2:405-426.

Gentner, S.-R. 1973. Aquatic vegetation of the Ottawa River near Chalk River Nuclear Laboratories (CRNL). AECL-4511.

Gentner, S.-R. 1977. Uptake and transport of iron and phosphate by Vallisneria spiralis L. Aquatic Botany 3, 267-272.

Grobbelaar, J.U. and P. Stegmann. 1976. Biological assessment of the euphotic zone in a turbid man-made lake. Hydrobiologia 48(3):263-266.

Gustafson, T.D. and M.S. Adams. 1973. The remote sensing of aquatic macrophytes. Report No. 24. Univ. of Wisconsin, Madison. 25 p.

Gustafson, T.D. and M.S. Adams. 1973. Remote sensing of Myriophyllum Spicatum L. in a shallow, eutrophic lake. In Remote Sensing and Water Resources Management, Am. Water Resources Assoc. Proc. No.17, 387-391.

Hamilton, P. and K.B. Macdonald. 1980. Estuarine and wetland processes with emphasis on modeling. Limnol. Oceanogr. 27(2): 395-396.

Heisey, R.M. and A.W.H. Damman. 1982a. Copper and lead uptake by aquatic macrophytes in Eastern Connecticut, U.S.A. Aquatic Botany 14:213-229.

Heisey, R.M. and A.W.H. Damman. 1982b. Biomass and production of Pontederia cordata and Potamogeton epihydrus in three Connecticut rivers. Amer. J. Bot. 69(5):855-864.

Holcomb, D.E., W.L. Wegener and V.P. Williams. 1975. Lake level fluctuation for habitat management. In P.L. Brezonik and J.L. Fox (eds.). Proc. Symp. on Water Quality Management Through Biological Control. Univ. of Florida, Gainesville, Jan. 29-31. pp. 151-157.

Hutchinson, G.E. 1957. A Treatise On Limnology. John Wiley & Sons, Inc., New York N.Y. 1015 p.

Huebert, D.B. and P.R. Gorham. 1983. Biphasic mineral nutrition of the submersed aquatic macrophyte Potamogeton pectinatus L. Aquatic Botany 16: 269-284

Hyatt, R.A. 1982a. Summer and Winter Creel Census on Rondeau Bay Lake Erie. 1981. Lake Erie Fisheries Assessment Unit Report 1982-2. Ontario Ministry of Natural Resources. 53p.

Jones, T.W., W.M. Kemp, J.C. Stevenson and J.C. Means. 1982. Degradation of atrazine in estuarine water/sediment systems and selected soils. J. Environ. Qual. 11: 632-638.

Jones, R.C. K. Walti, and M.S. Adams. 1983. Phytoplankton as a factor in the decline of the submersed macrophyte Myriophyllum spicatum L. in Lake Wingra, Wisconsin, U.S.A. Hydrobiologia 107:213-219.

Jupp, B.P. and D.H.N. Spence. 1977. Limitations of macrophytes in a eutrophic lake, Loch Leven. I.Effects of Phytoplankton. J.Ecol. 65:175-186.

Jupp, B.P. and D.H.N Spence. 1977. Limitations of macrophytes in a eutrophic lake, Loch Leven. II. Wave Action, sediments and waterfowl grazing. J. Ecol. 65. 431-446.

Kemp, W.M., J.C. Means, T.W. Jones, and J.C. Stevenson. 1982. Herbicides in Chesapeake Bay and their effects on submerged aquatic vegetation. In: E.G. Macalaster, D.A. Barker, and M. Kasper (eds.) Chesapeake Bay program technical studies: A synthesis. U.S. Environmental Protection Agency, Washington, D.C. 503-567

Kemp, W.M., W.R. Boynton, J.C. Stevenson, and J.C. Means. 1981. Submerged aquatic vegetation in Chesapeake Bay. Univ. Md. Center Environ. Estuar.Stud., Ref. No. HPEL-81-28, Cambridge, MD.

Kemp, W.M., W.R. Boynton, R.R. Twilley, J.C. Stevenson, and J.C. Means. 1982 Submerged aquatic vegetation in upper Chesapeake Bay. Final Report Univ. Md. Center Environ. Estuar. Stud. Ref. No. HPEL 82-193, Cambridge, MD.

Kenworthy, W.J. and M. Fonseca. 1977. Reciprocal transplant of the seagrass Zostera marina L. Effect of substrate on growth. Aquaculture 12:197-213.

Kiorboe, T. 1980. Distribution and production of submerged macrophytes in Tippen Grund, and the impact of waterfowl grazing. J. Appl. Ecol. 17: 675-687.

Knopf, R.R. 1984. Habitat modules: A new fish management tool. Unpubulished material for Berkley & Company, Inc. Spirit Lake, IA.

Lind, C.T. and G. Cottam. 1969. The submerged aquatics of University Bay: A Study in Eutrophication. The American Midland Naturalist 81(2):353-369.

Mann, D. and J.P. Coakley. 1978. An Annotated Bibliography of the Geology and Geomorphology of the Rondeau Peninsula and Environs. Canada Centre for Inland Waters, Unpublished report. 89p.

Marcus, B.A. 1980. Relationship between light intensity and chlorophyll content in Myriophyllum spicatum L. in Canadice Lake (New York, USA). Aquatic Botany 9:169-172.

Mayer, T. and J.D.H. Williams. 1981. Modified procedure for determining the forms of phosphorus in freshwater sediments. Technical bulletin no. 119. 8 p.

McCombie, A.M. and I. Wile. 1971. Ecology of aquatic vascular plants in southern Ontario impoundments. Weed Science 19(3):225-228.

McMillan, C. 1983. Seed germination for an annual form of Zostera marina from the Sea of Cortez, Mexico. Aquatic Botany 16:105-110.

Means, J.C., R. Wijayaratne and W.R. Boynton. 1983. Fate and transport of selected pesticides in estuarine environments: Implications for ocean pollution. Can.J. Fish.Aquat. Sci. (In press).

Menzie, C.A. 1979. Growth of the aquatic plant Myriophyllum spicatum in a littoral area of the Hudson River estuary. Aquatic Botany 6:365-375.

Newby, L.C., R.A. Kahrs, K. Adams and M. Szolics. 1978. Atrazine residues in the Chesapeake Bay. Proc. N.E. Weed Sci. Soc. 32: 339 (Abstract).

Nichols, Stanley A. 1973. The effects of harvesting aquatic macrophytes on algae. Wisconsin Academy of Sciences, Arts & Letters 61:165-171.

Oglesby, R.T., A. Vogel, J.H. Peverly, and R. Johnson. 1976. Changes in submerged plants at the south end of Cayuga Lake following tropical storm agnes. Hydrobiologia vol.48,3:251-255.

Ontario Ministry of the Environment. 1982. Water Quality Studies of Rondeau Bay and Watershed - Kent County. Prepared for: Ontario Ministry of the Environment. 57p.

Orth, R.J. and K.A. Moore. No date. The Biology and Propogation of Zostera marina, Eelgrass, In the Chesapeake Bay, Virginia. Special Report Number 265 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science. 187p.

Orth, R.J. and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science 222:51-53

Orth, R.J. and K.A. Moore. No date. The effect of fertilizers on transplanted eelgrass, Zostera Marina L., in the Chesapeake Bay. Proc. Ninth Annual Conference on Wetlands Restoration and Creation (in press).

Peltier, W.H. and Welch, E.B. 1969. Factors affecting growth of rooted aquatic plants in a reservoir. Weed Science 18:7-9.

Pentland, R.L. 1968. Runoff characteristics in the Great Lakes basin. Proc. 11th Conf. Great Lakes Res.: 326-359.

Phillips, R.C. 1974. Transplantation of seagrasses with special emphasis on eelgrass, Zostera marina L. Aquaculture 4:161-176.

Phillips, G.L., D. Eminson and G. Moss. 1978. A mechanism to account for macrophyte decline in progressively euthrophicated freshwaters. Aquat. Bot. 4: 103-126.

Phillips, R.C., W.S. Grant and C.P. McRoy. 1983. Reproductive strategies of eelgrass (Zostera Marina L.). Aquatic Botany 16:1-20.

Pip, Eva. 1978. A survey of the ecology and composition of submerged aquatic snail - plant communities. Can. J. Zool. 56:2263-2279.

Pip, Eva. 1979. Survey of the ecology of submerged aquatic macrophytes in central Canada. Aquatic Botany 7:339-357.

Pip, Eva. 1983. Ecogeographical tolerance range variation in aquatic macrophytes. Hydrobiologia (1983) (in press).

Prentki, R.T., M.S. Adams, S.R. Carpenter, A Gasith, C.S. Smith and P.R. Weiler. 1979. The role of submersed weedbeds in internal loading and interconception of allochthonous materials in Lake Wingra, Wisconsin, USA. Arch. Hydrobiol./Suppl.57 2:221-250.

Robel, R.J. 1961. Water depth and turbidity in relation to growth of sago pondweed. J. Wildlife Management 25(4):436-438.

Roy, A.C. 1979. The water quality of selected lakes in the Arctic watershed of Ontario, Ontario Ministry of the Environment, Toronto, Ont. 95 pp.

Samsel, Jr. G. L. 1973. Effects of sedimentation on the algal flora of a small recreational impoundment. Water Resources Bulletin 9(6):1145-1150.

Sastroutomo, S.S. 1982. Summer biomass of aquatic macrophytes in relation to sediment characteristics in Lake Aino-Numa, Miyagi, Japan. J.Ecol.,32:45-55.

Sastroutomo, S.S. 1982. The role of turions in the re-establishment process of population in submerged species. Ecological review vol. 20, no. 1. pp. 1-13.

Sastroutomo, S.S. 1981. Germination of turions in Potamogeton berchtoldii. Bot. Gaz. 142(4):454-460.

Sastroutomo, S.S. 1980. Dormancy and germination in axillary turions of Hydrilla verticillata. Bot. Mag. Tokyo 93: 265-273.

Schenk, C. 1983. personal communication. Southwestern Region. Ontario Ministry of the Environment, London, Ontario.

Schiemer, F. 1979. Submerged macrophytes in the open lake. Distribution pattern, production and long term changes. 1979. In Neusiedlersee: The Limnology of a Shallow Lake in Central Europe. Dr. W. Junk bv Publishers, London. pp 236-250.

Sculthorpe, C.D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold (Publishers) Ltd. London.

Sosiak, A.J. and D.S. McLennan. 1975. Rondeau Harbour Survey. Ontario Ministry of Natural Resources unpublished report.

Spence, D.H.N. 1967. Factors controlling the distribution of freshwater macrophytes with particular reference to the Lochs of Scotland. J. Ecol. 55: 147-170.

Spence, D.H.N. and J. Chrystal. 1970. Photosynthesis and zonation of fresh-water macrophytes. I. Depth distribution and shade tolerance. New Phytol. 69:205-215.

Spence, D.H.N., and J. Chrystal. 1970. Photosynthesis and zonation of fresh-water macrophytes. II. Adaptability of species of deep and shallow water. New Phytol. 69:217-227.

Stevenson, J.C. and N.M. Confer. 1978. Summary of Available Information of Chesapeake Bay Submerged Vegetation.Prepared for: Fish and Wildlife Service, U.S. Department of the Interior. 335p.

Stuckey, R.L. 1971. Changes of vascular aquatic flowering plants during 70 years in Put-In-Bay Harbor, Lake Erie, Ohio. The Ohio Journal of Science, Vol.71, No.6: 322-342.

Switzer-Howse, K.D. 1982. Agricultural Management Practices for Improved Water Quality in the Canadian Great Lakes Basin. LRRI Contribution No. 82-10. Agriculture Canada. 116 p.

Sztramko, L. 1980 Summer Creel Census on Rondeau Bay Lake Erie, 1979. Lake Erie Fisheries Assessment Unit Report 1980-3. Ontario Ministry of Natural Resources. 42p.

Takeguchi, S. 1984. Personal communication. Sales representative for Fell Fab Products Limited, Hamilton, Ontario.

Thorhaug,A. and C.B. Austin. 1976. Restoration of seagrasses with economic analysis. Environmental Conservation 3(4):259-267.

Titus, J.E., and M.S. Adams. 1979a. Coexistence and the comparative light relations of the submersed macrophytes, Myriophyllum spicatum L. and Vallisneria americana Michx. Oecologia (Berl.) 40:273-286.

Titus, J.E., and M.S. Adams. 1979b. Comparative carbohydrate storage and utilization patterns in the submersed macrophytes, Myriophyllum spicatum and Vallisneria americana. The American Midland Naturalist 102(2):263-272.

Titus, J., R.A. Goldstein, M.S. Adams, J.B. Mankin, R.V. O'Neill, P.R. Weiler, Jr., H.H. Shugart, and R.S. Booth. 1975. A production model for Myriophyllum Spicatum L. Ecology 56: pp. 1129-1138.

University of Maine/University of New Hampshire Cooperative Institutional Sea Grant Program. No date. How to Build a Floating Tire Breakwater. Information Bulletin #1. 12p.

U.S. Army Coastal Engineering Research Center. 1977. Shore protection manual. Third edition, U.S. Government Printing Office, Washington, D.C.20402.

Wall, G.J., W.T. Dickinson, and L.J.P. van Vliet. 1979. Agricultural sources of fluvial suspended sediments. Prog. Wat. Tech. 11(6):481-499

Westwood, J. 1983. Personal communication. Southwestern region. Ontario Ministry of the Environment. London, Ontario.

Wile, I and A.M. McCombie. 1972. Growth of Aquatic Plants in Southern Ontario Impoundments in Relation to Phosphorus, Nitrogen and Other Factors. Ministry of Natural Resources, 99p.

Wilkinson, R.E. 1961. Effects of reduced sunlight on water stargrass (Heteranthera dubia). Weeds 9(1):457-462.

Wilkinson, R.E. 1963. Effects of light intensity and temperature on the growth of waterstargrass, coontail, and duckweed. Weeds 11(1):287-290

Wilkinson, R.W. No date. Effects of red-light intensity on the growth of waterstargrass, coontail, and duckweed. Weeds

Witzel, L. 1981. Summer and Winter Creel Census on Rondeau Bay, Lake Erie, 1980. Lake Erie Fisheries Assessment Unit Report 1881-3, Ontario Ministry of Natural Resources. 60p.

Wood, C.R., and C.H. Roovers. 1978. Summer Creel Census on Rondeau Bay Lake Erie 1977. Lake Erie Fisheries Assessment Unit Report 1978-1. Ontario Ministry of Natural Resources, Ontario, Canada. 34p.

Wu, T.L. 1980. Dissipation of the herbicides atrazine and alachlor in a Maryland corn field. J. Environ. Qual. 9: 459-465.

Zahnow, E.W. and J.C. Riggleman. 1980. Search for linuron residues in tributaries of the Chesapeake Bay. J. Agric. Food Chem. 28:974-978.

APPENDIX A

EXPERTS CONTACTED

LIST OF EXPERTS CONTACTED

NAME	AFFILIATION	RESPONDED (*)
M.S. Adams	Dept. of Botany University of Wisconsin, Madison, Wisconsin.	*
S.G. Aiken	Biosystematics Research Institute Ottawa, Ontario.	*
J.W. Barko	Environmental Laboratory U.S.A. Waterways Experiment Station Vicksburg, MS.	*
E. Pitt. Best	Limnological Institute Nieuwersluis, The Netherlands.	*
J.J. Boon	Biogeochemist FOM- Inst. for Atomic and Molecular Physics Amsterdam, The Netherlands.	*
C.G. Boone	U.S. Army Engineer Waterways Experiment Station Environmental Effects Lab. Vicksburg, Mississippi.	
H. Boston	Dept. of Civil Engineering University of Washington Seattle, Washington.	
W.R. Boynton	Centre for Environmental & Estuarine Studies Chesapeake Biological Laboratory University of Maryland. Solomons, Maryland.	*
A.C. Churchill	Dept. of Biology Adelphi University Garden City, New York.	*
T.A. Debusk	Woods Hole Oceanographic Institute Woods Hole, MA.	

NAME	AFFILIATION	RESPONDED (*)
C. den Hartog	Laboratory of Aquatic Ecology Catholic University Toernovield, The Netherlands.	
L.N. Eleuterius	Gulf Coast Research Laboratory Ocean Springs, Mississippi.	
E.W. Garbisch	Environmental Concern Inc. St.Michaels, Maryland.	
S.R. Gentner	Atomic Energy of Canada Ltd. Chalk River, Ontario.	*
W.W. Gregg	Dept. of Biology Idaho State University Pocatello, Idaho.	
M.D. Hanisak	Harbor Branch Foundation, Inc. Fort Pierce, Florida.	
R.M. Heisey	Pesticide Research Center Michigan State University.	*
W.M. Kemp	Horn Point Environmental Laboratories The University of Maryland Centre for Environmental & Estuarine Studies Cambridge, Maryland.	*
J.C. Kimbel	Dept. of Botany University of Texas.	
C.P. McRoy	Institute of Marine Science University of Alaska Fairbanks, Alaska.	
G.E. Miller	Ontario Ministry of the Environment Timmins, Ont.	*
P.R. Newroth	Littoral Resources Unit Water Management Branch Ministry of Environment Parliament Buildings Victoria, B.C. V8V 1X5	*

NAME	AFFILIATION	RESPONDED (*)
R.J. Orth	Associate Marine Scientist Virginia Institute of Marine Science Gloucester Point, Virginia.	
G.L. Phillips	School of Environmental Sciences University of East Anglia Norwich, Great Britain.	
R.C. Phillips	School of Natural and Mathematical Sciences Seattle Pacific University Seattle, Washington.	*
E. Pip	Dept. of Biology The University of Winnipeg Winnipeg, Manitoba.	*
S.S. Sastroutomo	Biological Institute Tohoku University Japan.	
H.-H. Schierup	Botanical Institute University of Aarhus Aarhus, Denmark.	
J.R. Schubel	Chesapeake Bay Institute The John Hopkins University Baltimore, Maryland.	
D. Solander	Institute of Limnology Uppsala, Sweden.	
Y. Waisel	Dept. of Botany Tel-Aviv University Tel Aviv, Israel.	*
R.L. Wetzel	Virginia Institute of Marine Science Gloucester Point, Virginia.	
R.G. Wetzel	Dept. of Botany Michigan State University.	*
I. Wile	Ontario Ministry of the Environment Toronto, Ontario.	*

NAME	AFFILIATION	RESPONDED (*)
R.E. Wilkinson	Plant Physiologist Georgia Experimental Station, Experiment, Georgia.	*
J.C. Zieman	National Coastal Ecosystems Team U.S. Fish and Wildlife Seurce Slidell, Louisiana.	

APPENDIX B

PARTICLE SIZE

DISTRIBUTION CURVES

JE Hanna
Associates Inc.

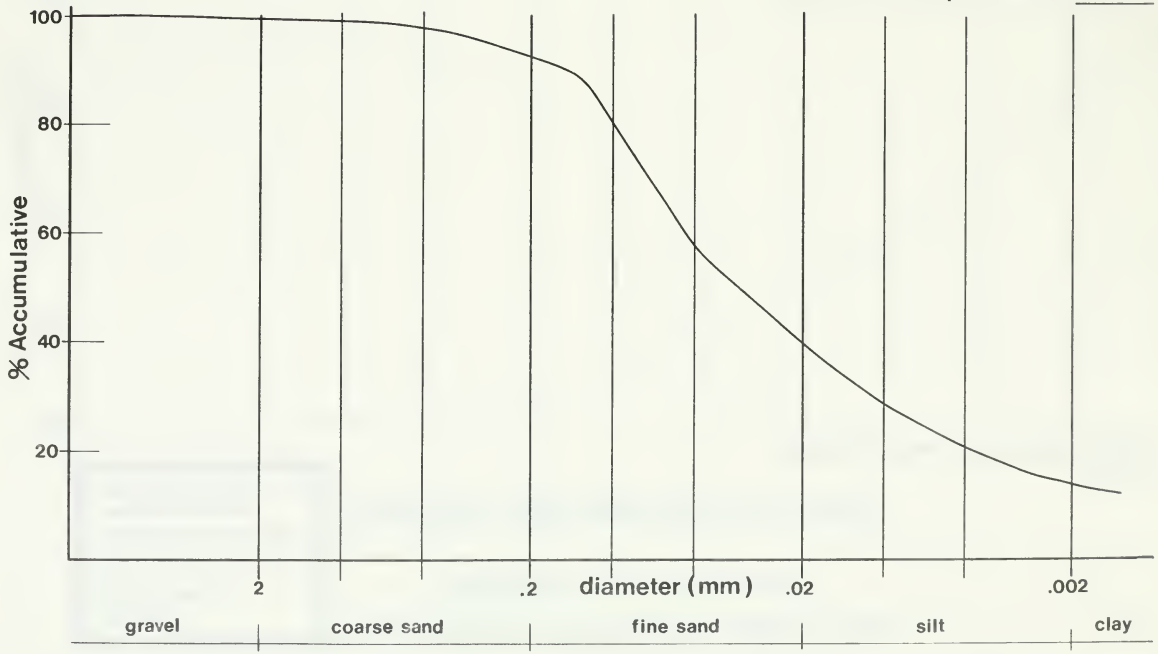
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau HI-11



JE Hanna
Associates Inc.

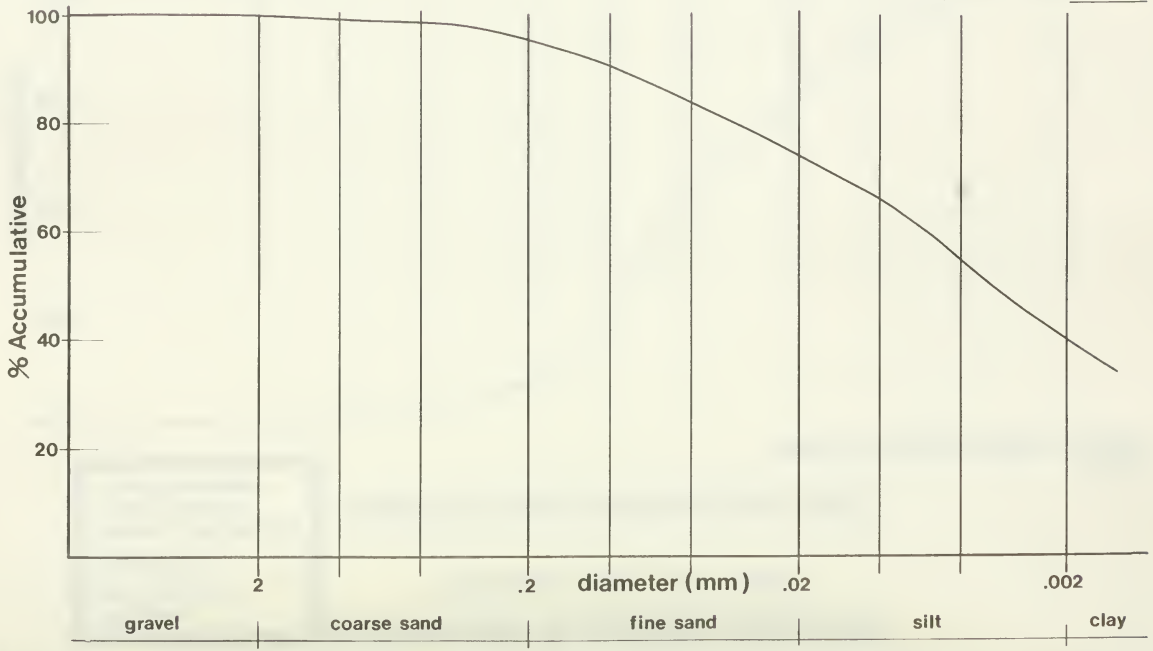
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau II-1



JE Hanna
Associates Inc.

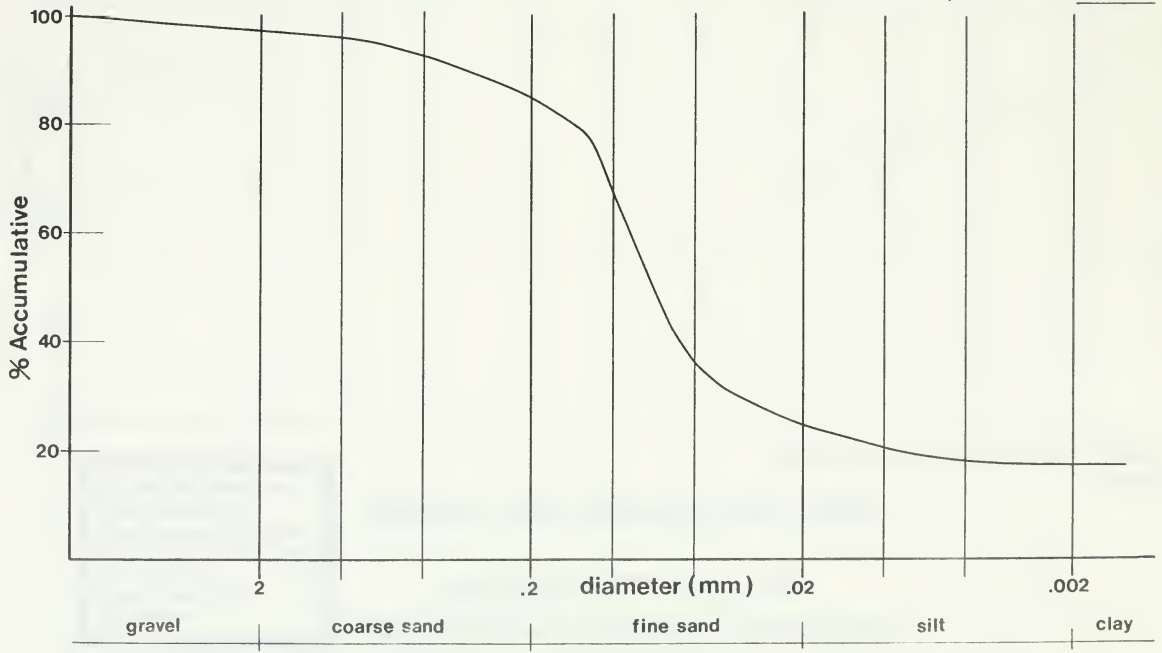
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau HI-1



JE Hanna Associates Inc.

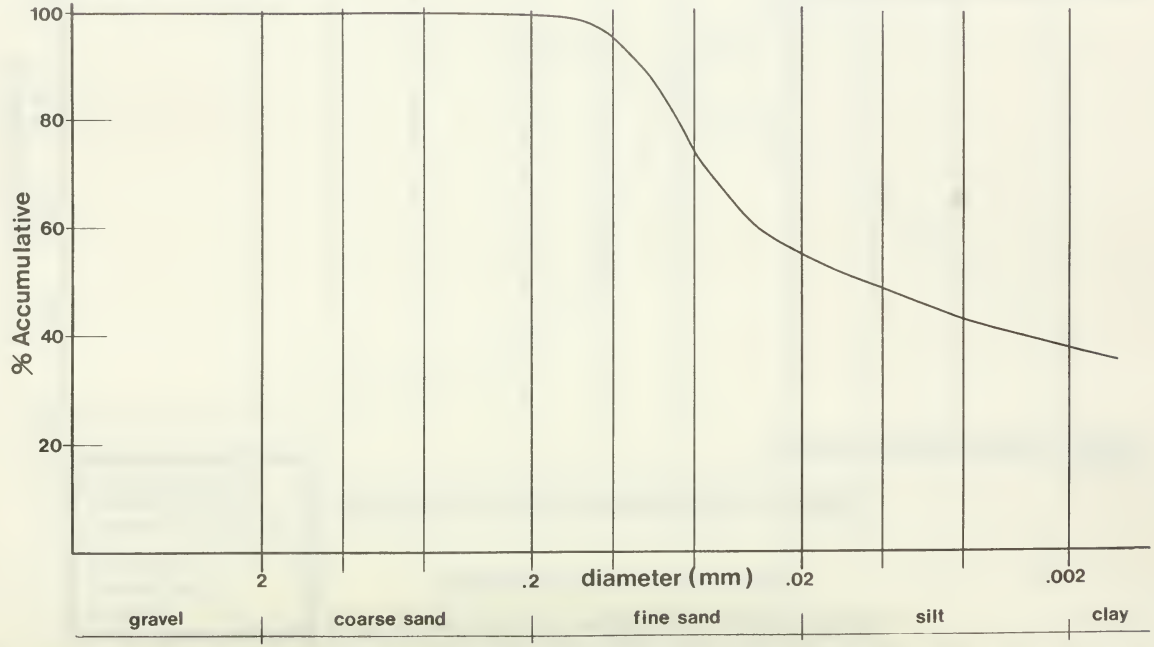
March 1984

Southwestern Region, Ontario Ministry of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau S-4



JE Hanna
Associates Inc.

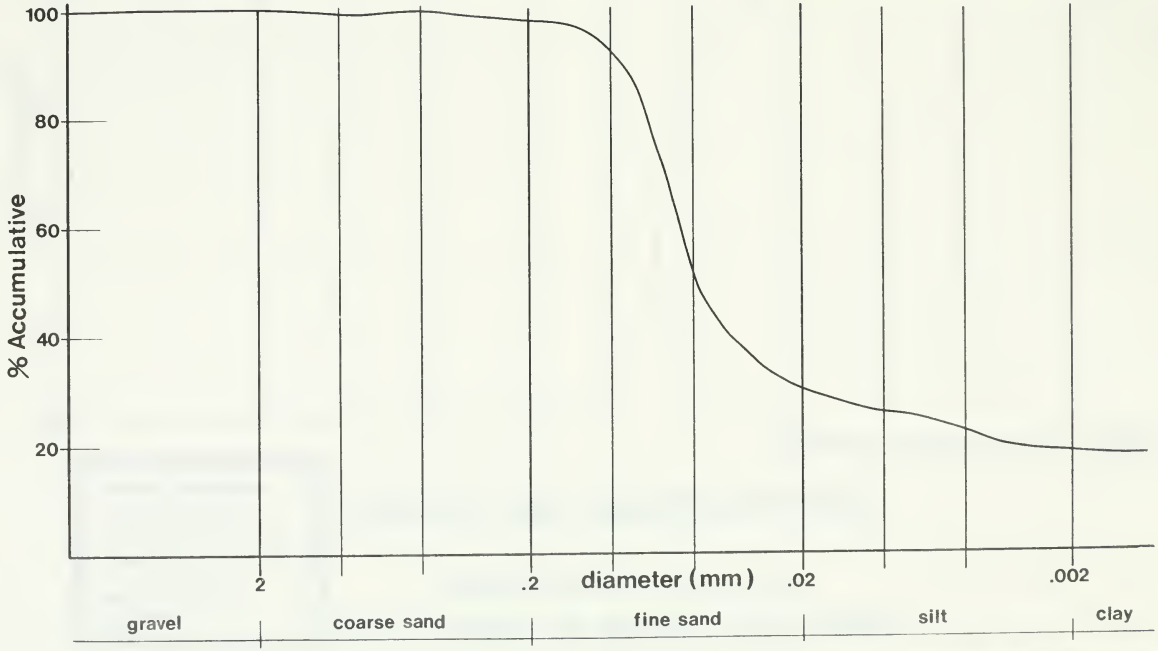
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau HI-6



JE Hanna
Associates Inc.

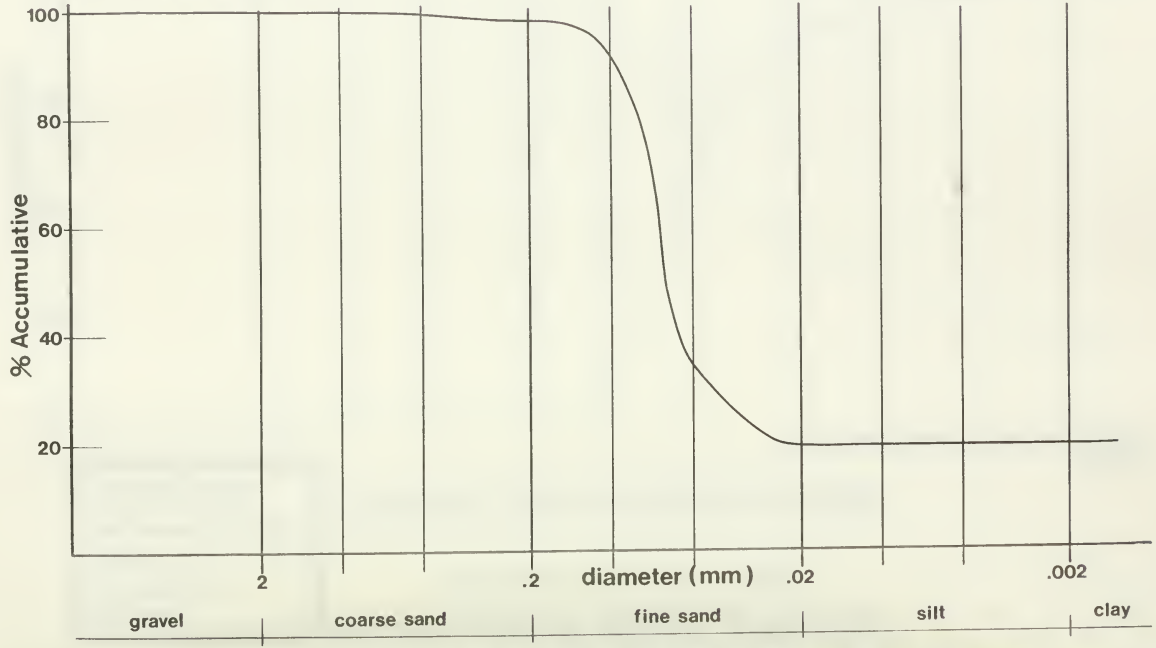
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau BC-6



JE Hanna Associates Inc.

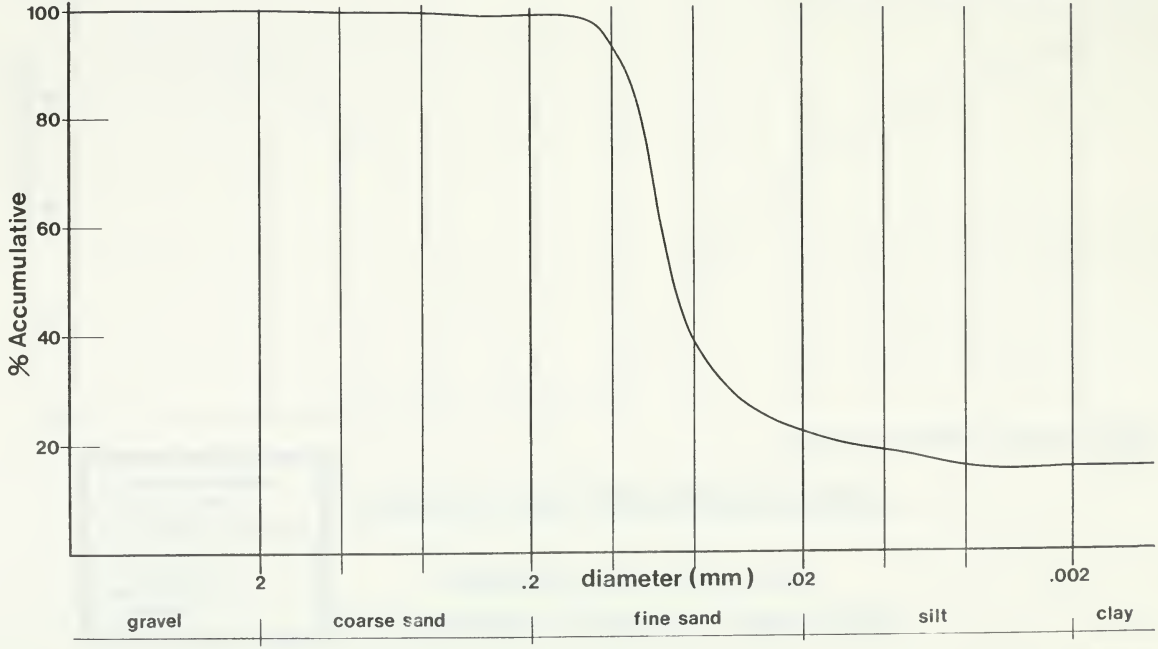
March 1984

Southwestern Region, Ontario Ministry of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau DE-7



JE Hanna
Associates Inc.

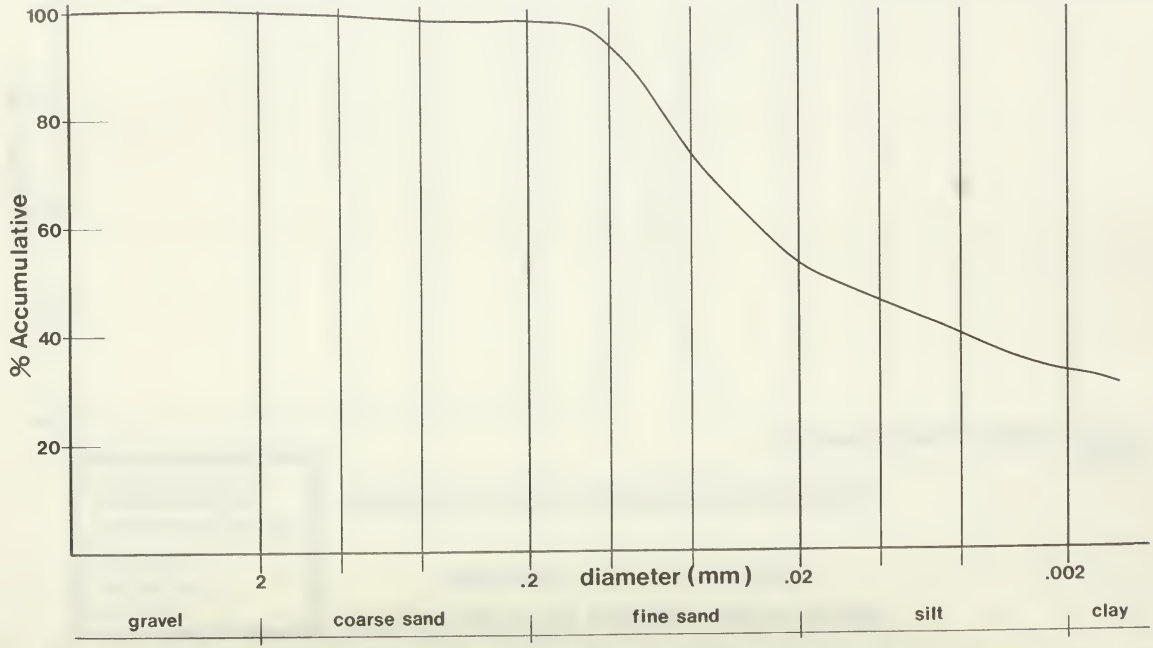
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau S-6



JE Hanna
Associates Inc.

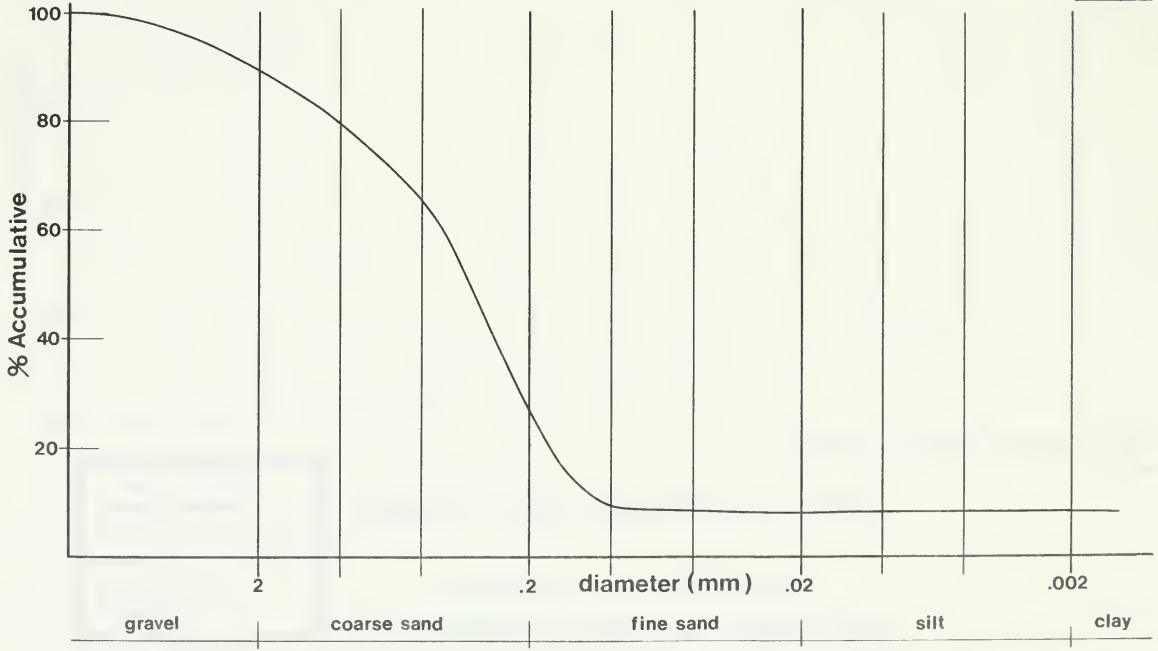
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau IA-4



JE Hanna
Associates Inc.

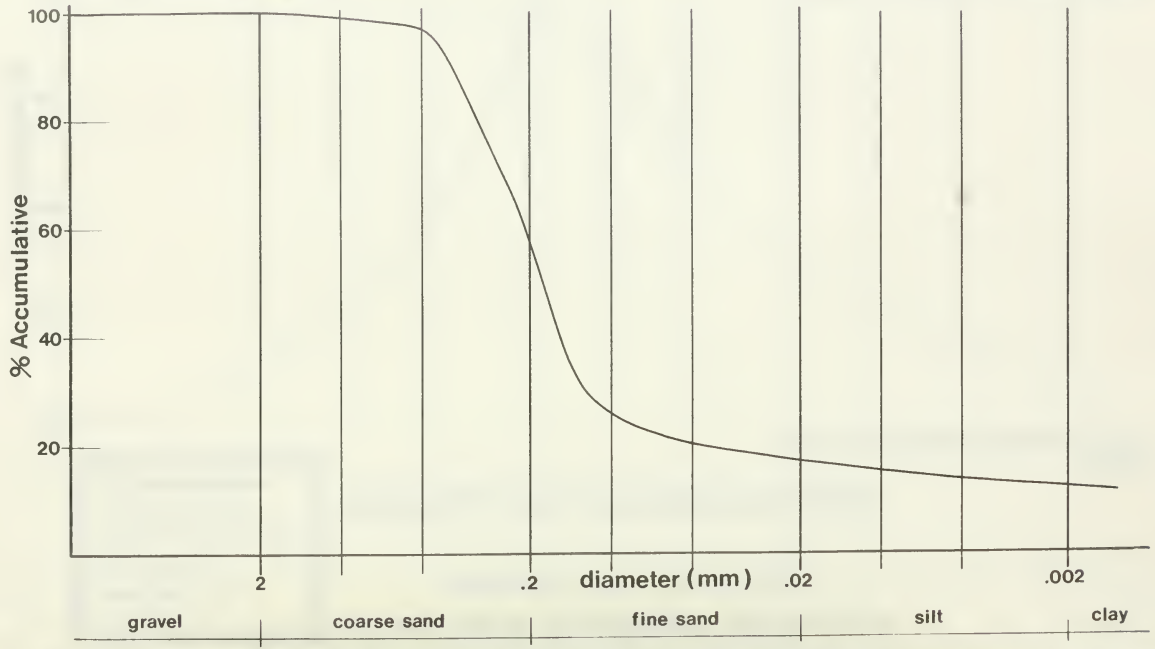
March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau IA-1



JE Hanna Associates Inc.

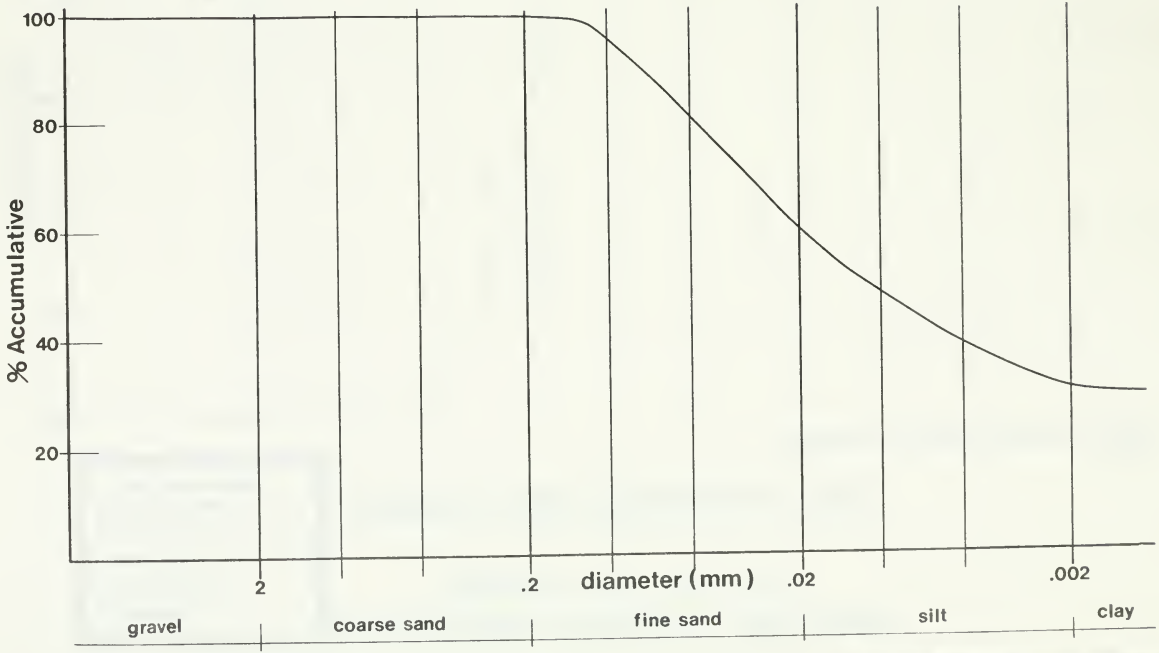
March 1984

Southwestern Region, Ontario Ministry of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE

Sediment Sample Station Rondeau KK-1



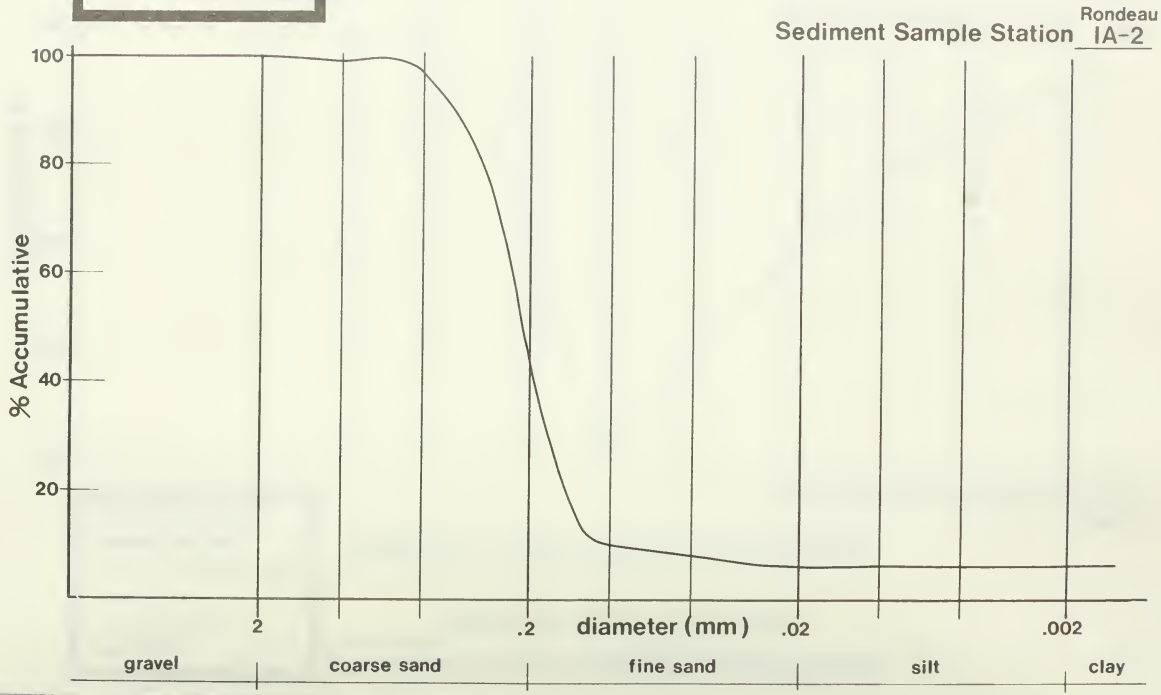
JE Hanna
Associates Inc.

March 1984

Southwestern Region,
Ontario Ministry
of the Environment

RESTORATION OF AQUATIC VEGETATION
RONDEAU BAY, LAKE ERIE

PARTICLE SIZE DISTRIBUTION CURVE



APPENDIX C

FIELD NOTES

WATER QUALITY

FIELD NOTES - WATER QUALITY SAMPLES

August 18, 1983

Sample Number	Sample Type*	Secchi Disc (m)	Water Depth (m)	Temp. (^{o}C)
1	G	.9	2.05	24
2	G	.15	1.75	26
3	G	.6	1.1	25
4	G	.55	1.9	25
5	G	.15	.98	26
6	G	.17	.98	27.2
7	G	.17	1.05	27.5
8	G	.23	.95	26
9	G	.14	1.0	27.2
10	G	.15	.7	27.7
11	G	.9	3.15	--
12	C	.9	3.15	--

General Comments:

- Wind 355^{o}N, light; .3m waves; overcast with sunny periods.
- Air temp. start 27.2^{o}C, finish 28^{o}C
- Time start 2:25, finish 6:15.
- Vallisneria americana and floating broad leaf Potamogeton spp. growing near Water Quality Station 2 in between .57 and .75 m of water. Dense beds, wave protected

* G - grab
C - composite

August 18, 1983

Sample Number	Sample Type	Secchi Disc (m)	Water Depth (m)	Temp. (^{o}C)	Comments
13	G	.65	1.9	24.5	
14	G	.28	1.1	24.2	sample taken at 10:00 a.m. winds calm
14a	G	.18	1.1	24.2	Wind south, 5-10 km, small whitecaps, sample taken at 5:30
15	G	.65	1.8	24.5	sample taken at 10:00 a.m. winds calm
15a	G	.55	1.8	24.5	sample taken at 10:00 a.m. wavy
16	G	.8	2.55	24.5	see 15
16a	G	.85	2.55	24.5	see 15a
17	G	.6	1.75	24.5	see 15
17a	G	.48	1.75	24.5	see 15a
18	G	.55	.8	24.5	see 15
18a	G	.25	.8	24.5	very turbid water out about 15 m from shore due to wave action. 5:30 SD.25 18a.
19	G	.8	2.95	25.1	
20	C	.8	2.95	25.1	
21	G	.25	1.3	25.2	onshore waves 5m
22	G	.15	.75	-	
23	G	.18	1.1	27.8	

August 18, 1983: continued

Sample Number	Sample Type	Secchi Disc (m)	Water Depth (m)	Temp. (^{o}C)	Comments
24	G	.09	.4	28.1	
25	G	.15	.6	28.1	
26	G	.05	.55	28.0	
27	G	.12	.7	29.4	
28	G	.8	2.0	-	

General Comments:

Potamogeton pectinatus beds from 3-20 stalks in 2.5m-2.8m of water parallel to shoreline past gatehouse to Shrewsbury dock.

- saw 8 different beds about 500m offshore driving a 6 hp at full throttle
- clear, light south wind, hazy with humidity
- air temp start 28^{o}C.

APPENDIX D

FIELD NOTES

VEGETATION SAMPLES

FIELD NOTES - VEGETATION SAMPLES

August 15, 1983 Quadrant 1

Transect	Length of Haul (m)	Depth (m)	Comments
1	10	1.3	sparse Myriophyllum
2	10	1.5	full of Heteranthera
3	10	1.5	few strands of Heteranthera
4	10	2.0	few strands of Heteranthera
5	10	2.05	empty sample
6	10	1.9	empty sample
7	10	1.8	full of Heteranthera
8	10	1.9	low density Heteranthera

General Comments:

- scattered dense beds of Heteranthera
- scattered single Myriophyllum specimens
- 1 patch of Vallisneria in shallow spot
- 1 Ceratophyllum demersum plant free-floating.

August 15, 1983 Quadrant 2

Transect	Length of Haul (m)	Depth (m)	Comments
9	10	2.6	empty (clam shells present)
10	10	2.1	empty
11	10	2.1	empty
12	10	1.1	few strands
13	10	.95	few strands
14	20	1.0	some
15	20	.95	empty
16	20	1.0	Najas, substrate clean and pebbly
17	20	1.3	sparse
18	20	1.3	empty

General comments:

- a few clumps of Potamogeton pectinatus rooted and floating at surface
- patches of Vallisneria near cattail shoreline.

Refer to Figure 17:

Note 1: At 1.6m few stalks of Potamogeton pectinatus growing to surface

Note 2: Myriophyllum strands growing

August 16, 1983 Quadrant 3

Transect	Length of Haul (m)	Depth (m)	Comments	Bearings Tree 1 (Degree N)	Cottage White 2 (Degree N)
19	20	2	sparse (floating)	162	334
20	30	1.6	sparse	174	338
21	30	1.5	some	--	--
22	30	1.55	full of Vallisneria not at surface	--	--
23	30	1.0-1.75	empty	--	--
				--	--
24	30	1.8	few strands unknown	--	--

August 16, 1983 Quadrant 4

Transect	Length of Haul (m)	Depth (m)	Comments
25	30	.9	sparse
26	30	.9	some
27	30	.9	some
28	30	1.1	sparse
29	30	1.2	one
30	30	1.4	empty
31	30	1.1	empty

General Comments:

- few beds of Vallisneria.

August 16, 1983 Quadrant 5

Transect	Length of Haul (m)	Depth (m)	Comments
32	30	1.45	empty
33	30	1.80	few strands
34	30	1.80	empty (full of soil)
35	30	1.1	empty
36	30	1.3	few strands
37	30	2.0	empty
38	30	2.0	some

August 16, 1983 Quadrant 6

Transect	Length of Haul (m)	Depth (m)	Comments
39	30	1.4	empty
40	30	.95	empty
41	30	1.2	empty
42	30	1.1	empty

General Comments: 4 stalks of Myriophyllum rooted (not sampled).

August 16, 1983 Quadrant 7

Transect	Length of Haul (m)	Depth (m)	Comments	Bearings Tree 2 (Degree N)	Gate-house	Direction of Haul
43	30	1.85	some	80	352	--
44	30	2.05	moderate catch	78	352	--
45	30	2.35	full	88	333	--
46	30	2.75	few strands	82	333	--
47	30	2.35	empty	85	324	47
48	30	2.1	few strands	90	340	44
49	30	1.6	full	88	349	48
50	30	2.0	full	92	326	25
51	30	2.0	some	94	344	196
52	30	2.05	few strands	92	340	--
53	30	.95	moderate full	94	8	--
54	30	.9		--	--	--

August 16, 1983 Quadrant 8

Transect	Length of Haul (m)	Depth (m)	Comments	Tree 1	Bearings Gate-house (Degree N)	Direction of Haul
55	30	3.1	empty	88	287	20
56	30	3.2	empty	95	284	20

General comments:

- Marsh. Dense beds of Vallisneria and Chara.

August 16, 1983 Quadrant 9

Transect	Length of Haul (m)	Depth (m)	Comments	Tree 1	Bearings Light-house (Degree N)	Direction of Haul
57	30	1.35	full (organics)	57	254	57
58	10	1.1	very full (organics)	32	292	57
59	20	1.1	moderate (sandy substrate-sand bar)	324	248	57

APPENDIX E

FIELD NOTES

SEDIMENT SAMPLES

SEDIMENT SAMPLES

August 13, 1983

Sample A-B	Water Depth (m)	Core Length (cm)	Comments
1	1.3	--	50 yards off shore
2	1.4	--	250 yards off shore 2 Vallisneria plants
3	2.8	12	gumbo and sand
4	3.1	12	gumbo
5	3	no sample	gumbo
6	2.95	--	gumbo over clay
7	2.7	15	gumbo over clay
8	2.35	--	clay gumbo over thin organic
9	1.0	--	scattered stalks of Myriophyllum and sparse Vallisneria
10	1.35	--	

August 13, 1983.

Sample B-C	Water Depth (m)	Core Length (cm)	Comments	Bearings Tree 1 White Cottage (Degrees N)
1	1.45	--	very compact	
2	1.3	--	very compact	
3	.8	--	--	

August 14, 1983

4	2.15	--	A-clay B-silt	
5	2.0	12.5	A (bottom)-organics B (middle)-silt C (top) -silt	
6	1.8	18	highly compact silty clay with thin layer of brown silt	
7	1.6	13	compact silt	
8	2.25	--	compact silt	
9	2.2	--	--	

Sample B-C	Water Depth (m)	Core Length (cm)	Comments	Bearings Tree 1 (Degrees N)	Bearings White Cottage (Degrees N)
10	2.1	15	sandy - with "floc" layer on top		
11	2.25	no sample	- " -		
12	2.5	18	sand over gumbo	108	2
13	2.3	13	1/2" floc grey gumbo fibrous brown organics	100	13
14	1.5	17	sand over mainly fibrous organics		
15	2.1	10	3" silt over organics -Myriophyllum bed		
16	2.35	no sample	4" gumbo over fibrous organics		
17	2.4	12	loose gumbo & organic mixture		
18	2.5	15	mod. compact sand		
19	2.6	15	floc over sand over gumbo	84	1
20	2.9	15	similar to above		

August 15, 1983

Sample D-F	Water Depth (m)	Core Length (cm)	Comments	Bearings Tree 1 (Degrees N)	Bearings House 1 (Degrees N)
1	1.1	5 6	2 soil samples, sandy	212	328
2	1.6	10		--	--
3	2.7	12		--	--
4	2.8	13	P.pectinatus sample	202	5
5	2.8	15		200	6
6	2.5	17		197	42
7	2.1	18	very compact	194	338
8	1.95	20	wood in bottom - compact	--	--
9	1.6	20	compact	--	--
10	1.2	8	ooze	--	--

August 14, 1983

Sample F-G	Water Depth (m)	Core Length (cm)	Comments
1	1.0	6	
2	1.4	10	sandy; very compact; Myriophyllum bed
3	1.8	12	compact
4	1.15	22	sand & organics; compact

Sample H-I	Water Depth (m)	Core Length (cm)	Comments	Bearings Cottage 1 (Degree N)	Bearings Peninsula beside harbour mouth (Degree N)
			A (bottom), B (middle), C (top)		
1	1.7	20	very turbid beds of Heteranthera & Myriophyllum near drain outlet sand over organics		
2	1.7	20	in weed bed 3 layers, mainly silty ooze over organics		
3	2.15	20	more Heteranthera & Myriophyllum		
4	2.35	5	very hard grey clay	10	136
5	2.4	9	gumbo	16	130
6	2.6	10	grey silt over organics	362	134
7	2.85	5		346	132
8	2.95	20	gumbo	334	146
9	2.95	7	gumbo	322	172
10	3.1	15	gumbo	322	186
11	3.1	-		306	225
12	1.95	6	coarse sand & pebbles		
13	1.97	-			

August 14, 1983

Sample I-A	Water Depth (m)	Core Length (cm)	Comments
1	.6	10	sand & pebbles over sandy organics
2	2.4	10	sand
3	2.0	20	coarse sand; thin layer of organic at bottom; Vallisneria & Heteranthera
4	2.1	--	

August 18, 1983

Sample X-Z	Water Depth (m)	Core Length (cm)	Comments
1	1.1	17	3" sandy organics over 4" gumbo organics
2	1.1	15	same
3	1.1	no sample	same
4	1.0	15	sandier; no veg.

August 19, 1983

Sample JK	Water Depth (m)	Core Length (cm)	Comments	Bearings Tree 1 (Degree N)	Bearings House E (Degree N)
1	2.35	20	floc over gumbo over fibrous organic gumbo	213	325
2	2.4	23	mainly gumbo mod. hard. lots of floc over top	204	312
3	2.4	15	mod. hard gumbo with wide band of floc on top	208	314
4	2.4	15	mod. hard clay gumbo with floc	--	282

Sample S	Water Depth (m)	Secchi Disc (m)	Comments
1	1.2	.4	-- well decomposed organics over clay, thin brown layer of floc on top
2	1.95	.55	- extremely compact clay - brown and grey particles - very similar to clay on southside of Shrewsbury dock - top scoured clean, no floc
3	2.05	.55	1 cm. silt with a few sand particles over 8 cm. of moderately decomposed organics - moderately compact.
4	1.95	.55	5 cm. loose brown grey silt over compact grey clay 8 cm.
5	2.0	.55	0 - 6 cm. of loose sandy silt over compact grey and brown flecked clay
6	1.8	-	3 cm. brown silt over 4 cm. grey brown silt over 5 cm. of brown and grey flecked compact clay
7	.9	-	scoured compact brown and grey flecked clay, no sample.
8	1.8	-	loose silt 4 cm. over loose organic silt 8 cm.

APPENDIX F

FIELD NOTES

DRAIN SEDIMENT SAMPLES

DRAIN SEDIMENT SAMPLES

August 17, 1983

Sample AA	Water Depth (m)	Comments
1	.5	beside road
2	1.75	in between
3	1.75	middle of stream

General comments:

- very turbid water 5'5"
- vegetation at shore consisting of Lemna minor and Nymphoides
- shrubs, goldenrod, grass
- corn fields, onion fields, soya, etc.
- gumbo clay with floc on top.

Note: - located where ditch turns from road
- algal bloom and aquatics given pollution

Sample BB	Water Depth (m)	Comments
4	.3	compact clay, less gumbo, pebbles on top
5	.75	same, no pebbles on top
6	1.0	gumbo ooze soft

General comments:

- field on one side
- cattails/Scirpus on other side
- Lemna/Nymphoides along shore.

Sample CC	Water Depth (m)	Comments
7	.6	clay with gravel
8	.8	gumbo, *Ceratophyllum demersum*, *Lemna* ooze with floc on top
9	1	*Potamogeton pectinatus*, floc over ooze, gumbo over gravel, sandy clay

General comments:

- willow/cattails on one side.
- lawn on the other side

Sample DD	Water Depth (m)	Comments
10	.6	floc over gumbo over hard clay
11	1.2	silty floc over gumbo over hard ooze & clay
12	1.6	silty floc over gumbo, ooze

General comments:

- *Polygonum* bank and soya field on one side
- cattails & field on other

Sample EE	Water Depth (m)	Comments
13	1.3	floc over gumbo over organics & clay
14	2.0	floc over gumbo clay

General comments:

- cattails on both side of ditch at road
- *Nymphoides*, *Lemna* at edge

Sample FF	Water Depth (m)	Comments
15	.4	silty clay with floc over top
16	.8	floc over hard clay gumbo
17	1.0	floc over mod. hard clay gumbo

Sample GG	Water Depth (m)	Comments
1 - (centre)	.2	corer penetrated .2m
2 - (N. bank)	.9	more compact, penetrated .2m
3 - (S. bank)	.8	loose, similar to 1

Sample HH	Water Depth (m)	Comments
1	-	uniform across bed - corer penetrated about .4m light brown floc on top of sediments.

Sample II	Water Depth (m)	Comments
1		4 cm brown floc silt over gray brown silty clay 8-12cm over well decomposed organics cover penetrated .6m easily, uniform across drain.

Sample JJ	Water Depth (m)	Comments
1 - (centre)	.55	2cm loose brown scoured silt over 6cm grey silt over 5cm moderately compact grey silty clay
2 - (south)	.4	3cm loose brown silt over 4 cm grey silt over 6cm fibrous organics, moderately loose.
3 - (north)	.7	2cm loose brown silt over 5cm grey brown silt over 5cm grey black organics

Sample KK	Water Depth (m)	Comments
1	.7	3cm loose brown silt over moderately compact grey brown silty clay with organic fibers
2	.4	south bank - some except brown silt layer 4cm
3	.5	north - brown silt 5cm over grey brown silt moderately packed blackish grey clay sample taken

APPENDIX G

FIELD NOTES

REPRESENTATIVE CORES

REPRESENTATIVE CORES

August 20, 1983

Sample	Depth (m)	Comments
1	2.3	moderately compact sand
2	2.6	floc over sand over gumbo
3	3.0	deep water
4	1.0	compact silt
5	2.05	floc over clay
6	1.95	floc over ooze

APPENDIX H

FIELD NOTES

SEED BANK SAMPLES

SEED BANK SAMPLES

August 18, 1983

Sample	Water Depth (m)	Comments	Bearings Tree 1 (Degree N)	Lighthouse 1 (Degree N)
Quadrant 9				
1	1.1	sand and organic	34	252
2	1.1	sand and organic	17	260
3	1.0	sand and organic	332	254
4	1.0	sand and organic	13	256

Quadrant 3

Sample	Water Depth (m)	Comments	Tree 1 (Degree N)	Tree by Burkes (Degree N)
5	-	gumbo	202	259
6	-	gumbo	210	253
7	-	sandy with pebbles, no organics	202	254
8	-	organics with sand, some pebbles - Vallisneria	212	260

Quadrant 4

9	-	organics
10	-	organics
11	-	very sandy with some pebbles
12	-	very sandy with some pebbles

Quadrant 5

13
14
15
16

Sample	Water Depth (m)	Comments
Quadrant 6		
17	1.1	gumbo
18	1.7	hard clay
19	1.8	hard clay
20	1.05	compact clay

Sample	Water Depth (m)	Comments	Bearings Tree 1 (Degree N)	Bearings Burke's Tree (Degree N)
Quadrant 2				
21	1.1	sandy clay	130	211
22	1.05	fibrous organic with sandy silt on top	120	211
23	.9	hard clay with floc on top	127	204
24	1.35	gumbo with a few pebbles	125	216

Quadrant 1 Sample	Water Depth (m)	Comments	Tree 1 (Degree N)	Gatehouse (Degree N)
25	1.4	sandy silt	100	200
26	2.0	sandy gumbo	105	204
27	.5	ooze	94	196
28	.9	gumbo	98	197
29	1.6	ooze	92	350
30	2.1	ooze	90	342
31	2.6	ooze	82	247

APPENDIX I

FIELD NOTES

GROWTH MEDIUM SEDIMENT SAMPLES

GROWTH MEDIUM SEDIMENT SAMPLES

August , 1983

Sample	Date	Location	Comments
1	Aug. 18	Quadrant 9	in dense Vallisneria bed sand & organics
2	Aug. 19	Quadrant 3	gumbo
3	Aug. 19	near I-A-2 and I-A-3	sand
4	Aug. 19	near Quadrant 5	deep water sample (ooze)
5	Aug. 19	near Quadrant 1	

APPENDIX J

GROWTH EXPERIMENTS

SUMMARY OF RESULTS

GROWTH EXPERIMENTS RESULTS
BIOMASS ANALYSIS

REDUCED LIGHT
(comparable to 2.15 m depth)

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
1PA-1	1.02	0.65	3	4	3	0	
1PA-2	1.33	0.02	-	-	-	-	*unsprouted
1PA-3	1.53	2.61	8	10	4	1	
1PB-1	1.93	1.7	6	5	4	1	
1PB-2	1.84	2.39	2	4	6	1	
1PB-3	1.43	1.68	3	4	3	1	
2PA-1	1.19	2.01	5	5	3	1	
2PA-2	0.98	2.13	4	3	3	1	
2PA-3	0.64	.76	4	3	3	1	
2PB-1	2.37	2.75	3	3	11	2	
2PB-2	1.93	1.75	4	5	5	1	
2PB-3	0.68	3.45	3	4	5	1	
3PA-1	1.09	1.15	>10	10	2	-	
3PA-2	2.31	1.47	0	-	3	-	
3PA-3	1.47	2.03	0	-	4	-	
3PB-1	1.17	1.27	5	2	2	1	
3PB-2	1.80	1.98	14	9	3	1	
3PB-3	2.40	1.1	10	5	4	1	
4PA-1	0.69	0.4	5	4	3	1	
4PA-2	1.60	2	6	4	4	1	
4PA-3	2.95	3.44	10	10	6	1	
4PB-1	1.82	1.88	10	10	4	1	
4PB-2	1.98	2.52	5	4	4	1	
4PB-3	1.56	0.04	-	-	-	-	*unsprouted
5PA-1	0.37	0.57	3	4	2	0	
5PA-2	0.62	0.75	3	5	2	1	
5PA-3	1.31	2.24	4	4	3	1	
5PB-1	0.61	0.77	3	6	2	0	
5PB-2	0.51	0.93	3	5	2	1	
5PB-3	1.36	1.29	3	4	2	1	
1VA-1	1.62	-1.32	>20	1	1	0	
1VA-2	2.49	-.97	>20	5	1	0	
1VA-3	1.82	-1.26	1	1	1	0	
1VB-1	0.86	-.28	8	3	1	0	
1VB-2	1.23	-.37	10	1	1	0	
1VB-3	3.85	-3.3	1	1	1	0	
2VA-1	1.60	-1.38	8	2	1	0	
2VA-2	1.87	-1.08	2	2	1	0	
2VA-3	1.80	-1.34	8	1	1	0	
2VB-1	1.70	-1.08	5	1.5	1	0	
2VB-2	1.73	-1.42	>20	3.5	1	0	*
2VB-3	1.27	-.63	>20	1.5	1	0	

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
3VA-1	1.72	-	-	-	-	-	**
3VA-2	1.28	-	10	4	-	-	**
3VA-3	4.93	-2.92	6	4	-	-	
3VB-1	2.53	-2.17	-	-	-	0	*only the tuber left
3VB-2	1.79	-	-	-	-	-	**
3VB-3	1.95	-1.42	5	2	1	0	
4VA-1	1.44	-1.01	15	2	1	0	
4VA-2	1.20	-.95	15	3	1	0	
4VA-3	0.96	-.48	15	3	1	0	
4VB-1	1.04	-.03	>20	3	1	0	
4VB-2	1.45	-1.15	>20	3	1	0	
4VB-3	3.31	-3.04	>20	3	1	0	*
5VA-1	1.42	-	-	-	-	-	**
5VA-2	4.10	-2.75	15	5.5	1	0	
5VA-3	0.91	-.49	15	3	1	0	
5VB-1	1.64	-1.34	15	3	1	0	
5VB-2	0.80	-.51	15	3	1	0	
5VB-3	1.53	-1.13	>20	3	1	0	
1HA-1	0.68	.09	4	14	1	0	
1HA-2	0.67	.08	4	17	1	0	
1HA-3	1.00	0	4	16	1	0	
1HB-1	1.05	-.05	5	24	1	0	
1HB-2	0.64	-.04	3	15	1	0	
1HB-3	1.04	-.1	4	16	1	0	
2HA-1	0.35	.02	8	12	1	0	
2HA-2	0.25	.07	4	12	1	0	
2HA-3	0.75	.02	4	6	1	0	
2HB-1	0.65	.04	10	16	1	0	
2HB-2	0.84	.01	10	16	1	0	
2HB-3	1.73	-.04	10	12	1	0	
3HA-1	0.49	-.03	3	16	1	0	
3HA-2	0.70	0	4	19	1	0	
3HA-3	1.07	-.05	7	22	1	0	
3HB-1	1.59	-.21	5	22	1	0	
3HB-2	0.62	.02	5	13	1	0	
3HB-3	0.81	.08	4	10	1	0	
4HA-1	0.46	.06	5	23	1	0	
4HA-2	0.74	.01	4	15	1	0	
4HA-3	0.83	.07	4	6	1	0	
4HB-1	1.53	-.21	>20	16	1	0	
4HB-2	0.52	-.03	4	14	1	0	
4HB-3	0.54	-.05	5	21	1	0	
5HA-1	0.37	.03	10	9	1	0	
5HA-2	0.62	.18	4	15	1	0	
5HA-3	0.82	.06	4	15	1	0	
5HB-1	0.87	.14	4	18	1	0	
5HB-2	0.34	.16	3	12	1	0	
5HB-3	0.89	.09	8	18	1	0	

GROWTH EXPERIMENTS RESULTS
BIOMASS ANALYSIS

NORMAL LIGHT
(comparable to 1.9 m depth)

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
1PA-1	1.74	1.75	3	8	4	1	
1PA-2	1.49	2.25	4	8	4	1	
1PA-3	1.90	3.26	3	4	4	1	
1PB-1	0.78	0.98	3	4	3	1	
1PB-2	3.20	2.0	6	20	7	1	
1PB-3	1.91	2.95	5	8	6	1	
2PA-1	0.78	0.03	-	-	-	-	*unsprouted
2PA-2	2.25	2.81	4	6	4	1	
2PA-3	1.01	1.21	2	4	3	1	
2PB-1	1.90	2.53	4	3	5	1	
2PB-2	2.09	2.32	4	3	5	1	
2PB-3	1.24	2.27	3	3	4	1	
3PA-1	2.05	1.48	4	4	3	1	
3PA-2	1.22	1.53	3	4	3	1	
3PA-3	1.22	2.15	4	3	5	1	
3PB-1	0.72	0.88	2	-	-	-	
3PB-2	0.79	0.94	-	-	-	-	*unsprouted
3PB-3	1.07	0.03	-	-	-	-	*unsprouted
4PA-1	3.30	2.75	3	20	9	3	
4PA-2	2.51	2.16	15	5	3	1	
4PA-3	2.40	2.2	5	5	3	2	
4PB-1	0.72	0.6	1	3	2	1	
4PB-2	1.03	1.49	6	3	3	1	
4PB-3	1.94	2.24	5	5	5	1	
5PA-1	2.01	3.87	8	12	10	2	
5PA-2	1.14	2.76	7	9	4	1	
5PA-3	2.53	-.31	8	6	4	1	
5PB-1	1.36	1.27	4	3	3	1	
5PB-2	1.24	2.17	3	4	4	1	
5PB-3	1.63	2.69	4	10	4	1	
1VA-1	0.87	-.63	>20	3	1	0	
1VA-2	0.75	-.45	>20	4.5	1	0	
1VA-3	0.60	-.49	20	3	1	0	
1VB-1	2.19	-2.09	15	2	1	0	*
1VB-2	1.93	-	-	-	-	-	**
1VB-3	2.39	-.32	>20	5	1	0	
2VA-1	0.70	-.29	5	1	1	0	
2VA-2	1.92	-1.59	15	1.5	1	0	*
2VA-3	1.45	-1.31	15	2	1	0	
2VB-1	1.17	-.92	15	2.5	1	0	
2VB-2	2.55	-2.02	5	1.5	1	0	
2VB-3	2.10	-1.83	0	-	1	0	

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
3VA-1	0.57	-	-	-	-	-	**
3VA-2	3.00	-1.63	>20	1.5	1	0	
3VA-3	1.93	-.73	5	2	1	0	
3VB-1	1.66	-1.02	15	1.5	1	0	
3VB-2	1.09	-.77	>20	1.5	1	0	
3VB-3	0.84	-.53	15	2	1	0	
4VA-1	1.85	-1.73	>20	2	1	0	*
4VA-2	0.76	.04	>20	2	1	0	*
4VA-3	2.22	-	-	-	-	-	**
4VB-1	1.40	-	-	-	-	-	**
4VB-2	2.90	-1.62	>20	3	1	0	
4VB-3	3.78	-1.68	>20	4	1	0	
5VA-1	1.02	-	-	-	-	-	**
5VA-2	1.67	-.79	>20	2	1	0	
5VA-3	1.23	-	-	-	-	-	**
5VB-1	1.09	-.79	15	1	1	0	
5VB-2	1.46	-1.0	15	1.5	1	0	
5VB-3	0.84	-	-	-	-	-	**
1HA-1	1.11	-.3	10	14	1	0	
1HA-2	0.14	.04	7	17	1	0	
1HA-3	0.60	-.04	0	-	1	0	
1HB-1	0.64	.08	5	17	1	0	
1HB-2	0.89	-.1	6	22	1	0	
1HB-3	0.44	-.15	6	6	1	0	
2HA-1	0.54	-.04	3	15	1	0	
2HA-2	0.36	.05	3	16	1	0	
2HA-3	0.57	0	10	4	1	0	
2HB-1	0.41	-.03	4	13	1	0	
2HB-2	1.33	-.22	>10	12	1	0	
2HB-3	1.13	-.05	4	20	1	0	
3HA-1	0.76	.01	5	9	1	0	
3HA-2	0.45	-.05	5	14	1	0	
3HA-3	1.12	-.01	4	7	1	0	
3HB-1	0.35	-.02	4	12	1	0	
3HB-2	0.67	-.11	8	9	1	0	
3HB-3	0.59	-.04	8	11	1	0	
4HA-1	0.41	-.03	5	15	1	0	
4HA-2	0.32	.03	3	16	1	0	
4HA-3	1.07	-.08	5	3	1	0	
4HB-1	0.13	-.07	2	8	1	0	
4HB-2	0.38	-.04	4	14	1	0	
4HB-3	0.50	.08	6	5	1	0	
5HA-1	0.56	0	3	13	1	0	
5HA-2	0.53	.05	6	21	1	0	*
5HA-3	0.50	0	2	11	1	0	
5HB-1	1.01	.04	3	13	1	0	
5HB-2	0.49	.03	5	9	1	0	
5HB-3	0.56	-.07	2	13	1	0	

GROWTH EXPERIMENTS RESULTS
BIOMASS ANALYSIS

INCREASED LIGHT
(comparative to 1.65 m depth)

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
1PA-1	1.12	1.03	3	3.3	3	1	
1PA-2	1.22	1.27	3	7.0	3	1	
1PA-3	2.63	3.08	5	18	5	1	
1PB-1	0.54	0.52	2	2	2	1	
1PB-2	0.67	0.75	2	4	3	1	
1PB-3	0.95	0.77	3	5	3	1	
2PA-1	1.46	3.19	7	6	5	1	
2PA-2	0.66	0.02	-	-	-	-	*unsprouted
2PA-3	0.78	0.62	0	-	2	2	
2PB-1	2.13	0.72	2	6	3	1	
2PB-2	1.16	0.7	3	4	2	1	
2PB-3	1.89	1.69	3	4	6	1	
3PA-1	1.15	0.09	-	-	-	-	*unsprouted
3PA-2	0.66	0.57	3	3.5	2	1	
3PA-3	1.55	0	-	-	-	-	*unsprouted
3PB-1	0.67	0.01	-	-	-	-	*unsprouted
3PB-2	0.52	0.79	3	3	2	1	
3PB-3	1.01	0	-	-	-	-	*unsprouted
4PA-1	1.10	1.99	3	1	3	1	
4PA-2	2.37	0	-	-	-	-	*unsprouted
4PA-3	2.01	1.59	4	10	3	1	
4PB-1	0.95	1.49	2	6	3	1	
4PB-2	1.71	1.47	4	4	4	1	
4PB-3	1.86	2.42	4	12	4	1	
5PA-1	0.98	0.87	3	3.5	2	1	
5PA-2	1.27	1.83	4	5	3	1	
5PA-3	0.79	0.59	0	-	4	1	
5PB-1	1.63	1.69	4	6	3	1	
5PB-2	1.65	2.67	5	10	5	1	
5PB-3	1.44	1.03	4	10	3	1	
1VA-1	0.83	-.68	>20	2	1	0	
1VA-2	1.44	-	-	-	-	-	**
1VA-3	0.67	-.41	10	2.5	1	0	
1VB-1	1.39	-.75	>20	2	1	0	
1VB-2	1.06	-.68	10	1	1	0	
1VB-3	1.10	-1.0	5	4	1	0	
2VA-1	0.70	-.47	15	1.5	1	0	*
2VA-2	0.43	-.33	15	1	1	0	
2VA-3	0.75	-.62	10	1	1	0	*
2VB-1	2.88	-2.32	10	3	1	0	
2VB-2	1.62	-1.13	15	1.5	1	0	
2VB-3	0.97	-.19	5	2	1	0	

Sample	Initial Weight (g)	Change in Weight (g)	Number of roots in soil	Average length of roots (cm)	Number of stalks	Number of rhizomes	Comments
3VA-1	0.85	-.77	2	1.0	1	0	
3VA-2	0.94	-.84	0	-	1	0	
3VA-3	0.79	-.67	0	-	1	0	*
3VB-1	0.85	-	-	-	-	-	**
3VB-2	1.15	-.41	>20	2	1	0	
3VB-3	0.99	-.63	15	1	1	0	
4VA-1	1.43	-.78	>20	1.5	1	0	
4VA-2	0.99	-.62	5	3	1	0	
4VA-3	0.61	-.35	5	2.5	1	0	
4VB-1	0.79	-.56	15	2	-	-	
4VB-2	0.55	-	-	-	-	-	**
4VB-3	0.73	-.48	15	0.5	1	0	
5VA-1	0.76	-.68	10	1.5	1	0	
5VA-2	0.51	-	-	-	-	-	**
5VA-3	0.84	-.38	>20	3	1	0	
5VB-1	0.69	-.52	5	1.5	1	0	
5VB-2	1.95	-1.3	15	2	1	0	
5VB-3	0.41	-.38	5	0.5	1	0	
1HA-1	0.56	-.06	2	16	1	0	
1HA-2	1.51	-.32	10	20	1	0	
1HA-3	0.66	-.08	10	9	1	0	
1HB-1	0.50	-.05	4	14	1	0	
1HB-2	0.92	-.07	8	12	1	0	
1HB-3	0.97	.02	5	5	1	0	
2HA-1	0.82	-.07	5	16	1	0	
2HA-2	0.93	.03	8	9	1	0	
2HA-3	0.23	.03	4	5	1	0	
2HB-1	0.90	.19	4	14	1	0	
2HB-2	1.49	.27	10	17	1	0	
2HB-3	0.24	0.03	4	5	1	0	
3HA-1	0.50	-.08	3	8	1	0	
3HA-2	1.00	.03	2	12	1	0	
3HA-3	0.34	.03	5	9	1	0	
3HB-1	1.01	.14	>10	10	1	0	
3HB-2	1.01	-.23	4	12	1	0	
3HB-3	0.86	-.06	8	11	1	0	
4HA-1	0.33	.05	1	4	1	0	
4HA-2	0.70	-.01	5	6	1	0	
4HA-3	0.89	.01	>10	10	1	0	
4HB-1	0.60	-.07	8	7	12	0	
4HB-2	0.65	.02	5	7	1	0	
4HB-3	0.24	-.02	5	5	1	0	
5HA-1	1.23	0	4	4	1	0	
5HA-2	0.36	.10	2	12	1	0	
5HA-3	1.43	0.11	5	13	1	0	
5HB-1	2.22	-.10	5	8	1	0	
5HB-2	0.40	.02	1	5	1	0	
5HB-3	1.29	.03	4	12	1	0	

* dead
** no living tissue remaining

Key:
Example: 1PA-1

1 - refers to soil type:
1 - compact glaciolacustrine clay
2 - deepwater well-decomposed organic silt
3 - silt
4 - coarse sand
5 - sandy organics

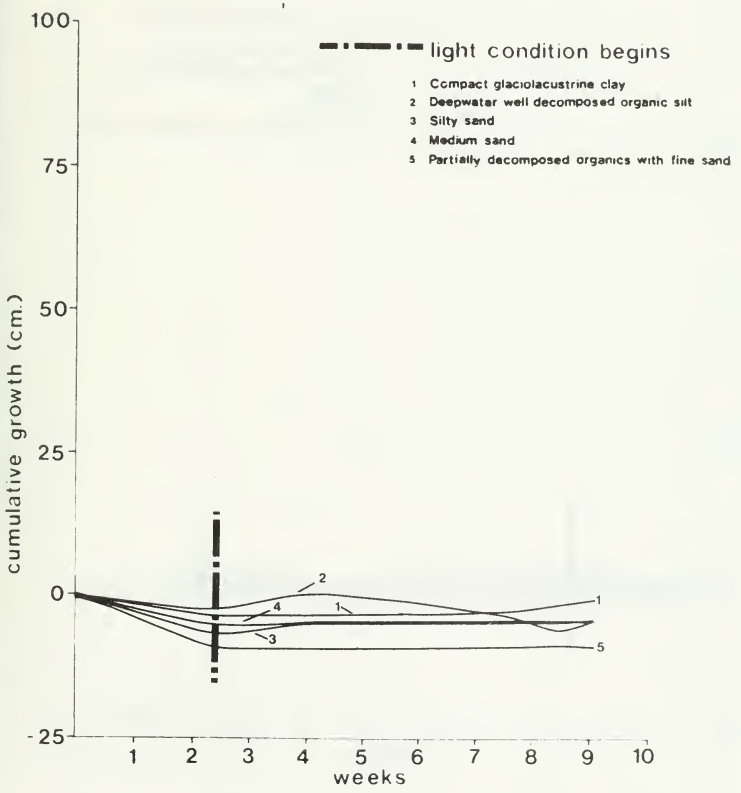
P - refers to species:
P - Potamogeton pectinatus
V - Vallisneria americana
H - Heteranthera dubia

A - for identification purposes only. Both A & B are identical in terms of plant species, soil type and light condition

1 - for identification purposes only. Refers to the position in the pot. There are three plants in each pot.

RESTORATION OF AQUATIC VEGETATION

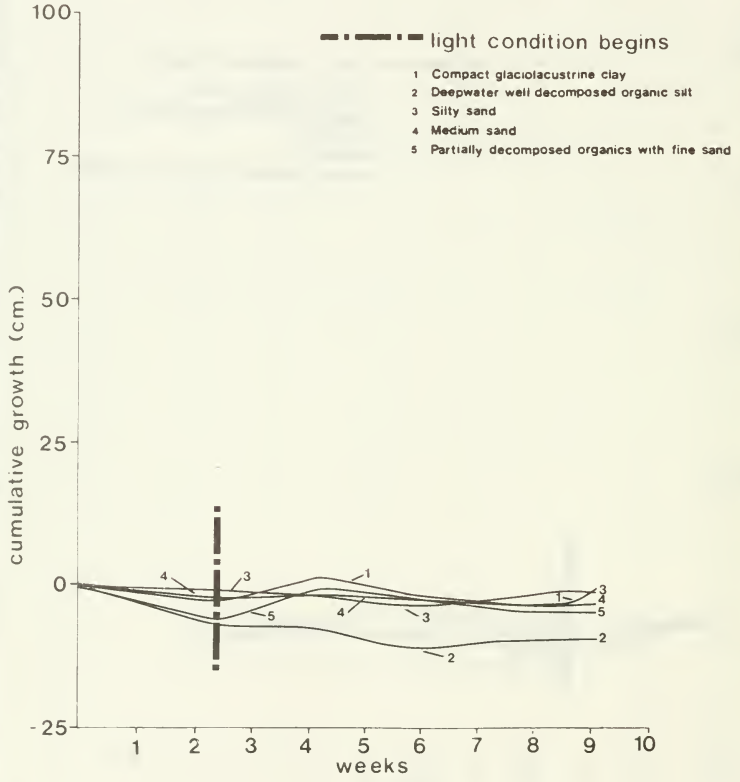
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH HETERANTHERA REDUCED LIGHT	FIG. 29

RESTORATION OF AQUATIC VEGETATION

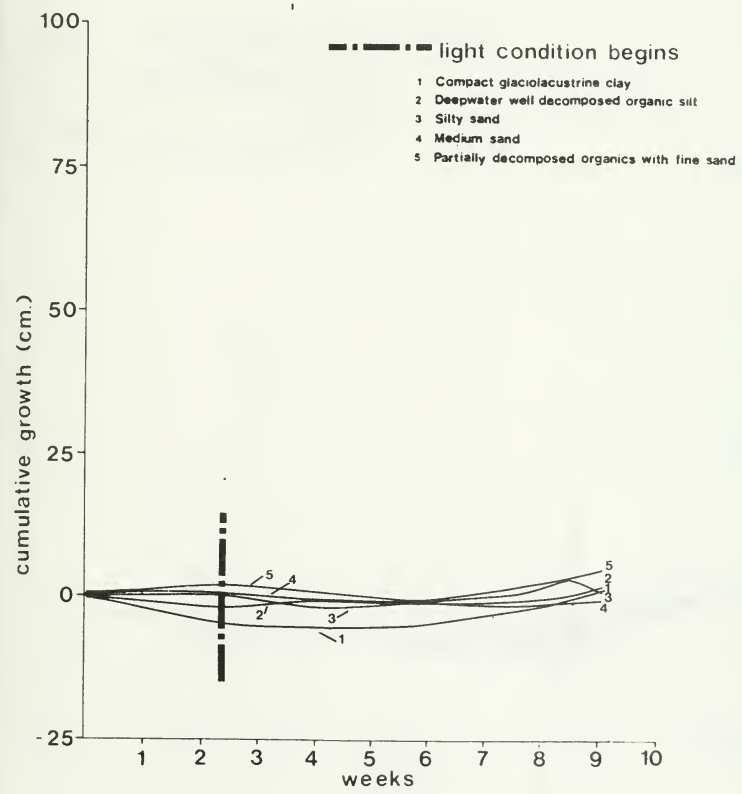
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH HETERANTHERA NORMAL LIGHT	FIG. 30

RESTORATION OF AQUATIC VEGETATION

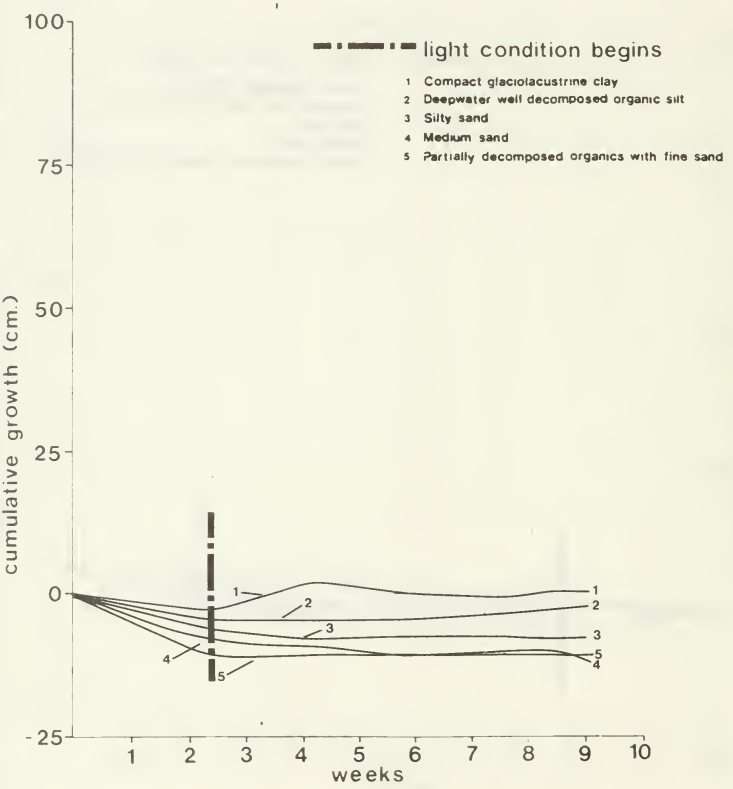
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH HETERANTHERA INCREASED LIGHT	FIG. 31

RESTORATION OF AQUATIC VEGETATION

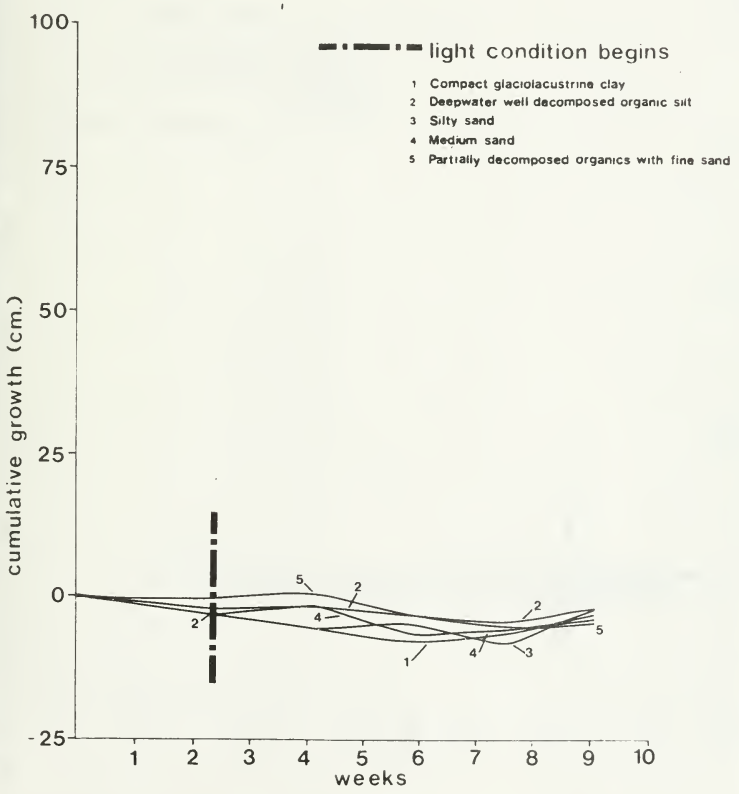
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH VALLISNERIA REDUCED LIGHT	FIG. 32

RESTORATION OF AQUATIC VEGETATION

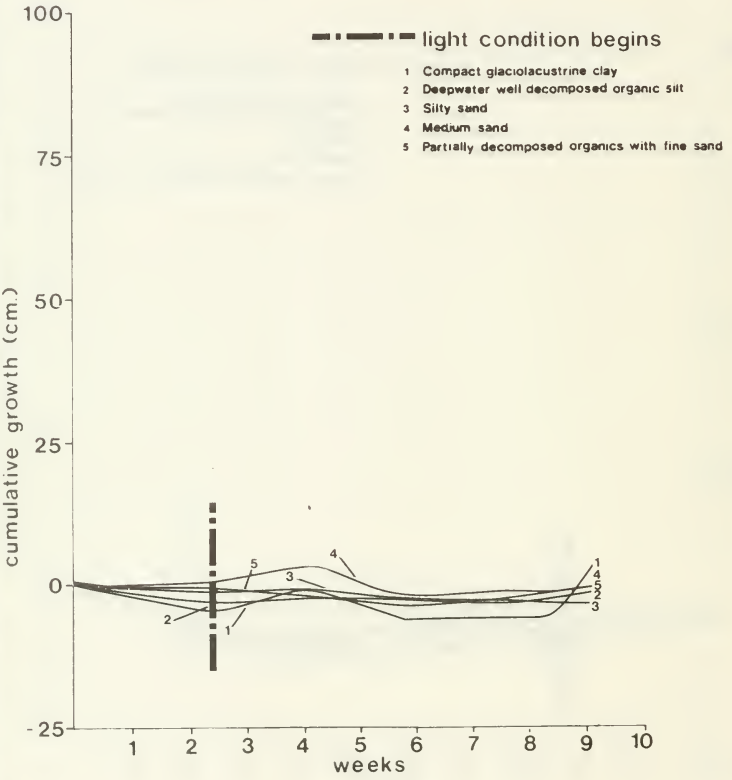
RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH VALLISNERIA NORMAL LIGHT	FIG. 33

RESTORATION OF AQUATIC VEGETATION

RONDEAU BAY, LAKE ERIE



JEHanna Associates Inc.	CUMULATIVE GROWTH VALLISNERIA INCREASED LIGHT	FIG. 34